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MEASURING EXTERNAL EFFECTS OF SOLID WASTE MANAGEMENT

INSTITUTE FOR POLICY ANALYSIS

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WASHINGTON ENVIRONMENTAL RESEARCH CENTER

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A survey of the technology of sanitary landfills suggests that a properly designed fill will cause very little air and water pollution, but may impose visual and noise pollution on nearby residents. These hypotheses are tested with data on property surrounding four sanitary landfills in Los Angeles County. A model of the determinants of residential property values is formulated and estimated. The model includes variables which describe the characteristics of the property and variables which describe the relationship of the property to the fill. Statistical estimates of the parameters of the model indicate that proximity to and view of a sanitary landfill do not significantly reduce the market or assessed value of surrounding property.

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MEASURING EXTERNAL EFFECTS OF SOLID WASTE MANAGEMENT

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CONCLUSIONS

1. Direct measurement of external costs and benefits is in principle feasible, but depends on having information which is typically unobtainable. Since perceived external effects will be reflected in property values, the analysis of the determinants of property values provides a method for approximating external costs and benefits. This indirect method has the advantage of requiring less extensive data.

2. Past empirical studies have demonstrated that pollution costs are in fact reflected in property values. A properly specified property value study can be expected to reveal the existence of significant environmental impacts that may be associated with solid waste disposal in sanitary landfills.

3. An important assumption of the indirect method of estimating the costs and benefits of external effects is that property owners fully comprehend the impact of such effects on them. The technology of sanitary landfills is such that little if any water or air pollution would result from a properly designed fill. The primary external effect,

if any, associated with a fill would take the form of noise and visual pollution. Since these effects would be readily perceived by property owners, a study of property values is an appropriate technique for measuring their costs.

4. A study of values of residential property adjacent to four sanitary landfills in Los Angeles County revealed a general lack of significant detrimental environmental effects. In the one case where truck noise associated with the fill had a negative effect on property values, both proximity and view of the fill had positive effects due presumably to the anticipated transformation of the fill to a recreational site.

5. The precision of the estimates of the costs and benefits of external effects is limited by the adequacy of information on the relationships between property values and non-environmental variables, such as the characteristics of structures. Further work on specification and estimation of these relationships is needed.

RECOMMENDATIONS

1. Since this study suggests that the social costs of properly designed sanitary landfills do not significantly exceed the direct costs to the municipality, there does not appear to be a case for discouraging the use of such fills.

2. Property value studies may be used as a technique for estimating the costs of environmental effects in those instances where property owners can be expected to have knowledge of the existence and consequences of such effects.

3. In order to improve the reliability with which the costs and benefits of environmental effects can be measured, further work on the specification and estimation of models of real estate values is desirable.

CHAPTER I

THE PRICE SYSTEM, MARKET IMPERFECTIONS, AND BENEFIT-COST ANALYSIS

A. INTRODUCTION AND OVERVIEW

It is not necessary to document the increasing importance to municipalities of the problem of disposing, or of otherwise processing, the solid waste generated within their boundaries. Governments, particularly at the local level, are faced with the choice of techniques to process and dispose of growing quantities of waste. In addition, they have the option of implementing policies to alter the flow or composition of waste, such as laws prohibiting certain non-return containers, or a law making residential garbage grinders compulsory, or even a fee on the quantity of waste generated by households. In deciding which policies and techniques to adopt as part of a waste management system, it is important that the policymakers understand the nature of an optimal decision, and particularly, the appropriate criteria by which to compare alternatives to make a socially optimal decision.

The purpose of economic theory is to analyze and clarify the nature of socially optimal decisions in the context of scarce resources. While the context is generally taken to be the supply of products which consumers buy in the marketplace, the theory is also applicable to such increasingly scarce goods as clean air, unpolluted streams, and pleasing views. In fact, the existence of such goods as these provides the general basis for this report. It is because the different techniques for disposing of solid waste require the "input" of such goods, in differing mixtures, that one must address the problem of how to weight these social costs, which are not "internalized" to the municipality, along with the ordinary costs, which are.

In this chapter, we briefly review the theory of efficient resource allocation; it is clearly necessary to understand the basic problem of externalities, which are, roughly speaking, costs of carrying on an activity which are not borne by the agent performing the activity. The problem of modifying benefit-cost analysis to account for externalities is then discussed, in particular the question of how to quantify such external costs, in units which are commensurate with the other benefit and cost measures. We also consider the nature of the equity considerations which are often glossed over in most benefit-cost analyses.

Chapter II provides a more rigorous review of several of these issues. Various approaches to the measurement and valuation of external effects are treated. The remainder of this chapter provides an introduction to that analysis.

Chapter III examines attempts that have been made to obtain actual estimates of the money value of externalities. Studies using both direct and indirect methods are discussed. Particular attention is paid to studies that employ data on property values or rents.

Chapter IV summarizes what is known about the physical manifestations of the externalities associated with solid waste management. It provides a survey of the literature with respect to both the qualitative nature and the quantitative importance of these effects. This material is important because in general, the better an economist understands the relevant technology, the more likely he is to base his analysis on defensible assumptions.

Chapter V relates the general principles of externality valuation presented in Chapters II and III to the realities of the solid waste problem, as outlined in Chapter IV. Some of the important practical problems of externality valuation in the solid waste context are considered.

Finally, Chapter VI presents the results of an empirical analysis of the external effects of four sanitary landfills in the Los Angeles area. The indirect method is used, and disaggregated data on property values are employed.

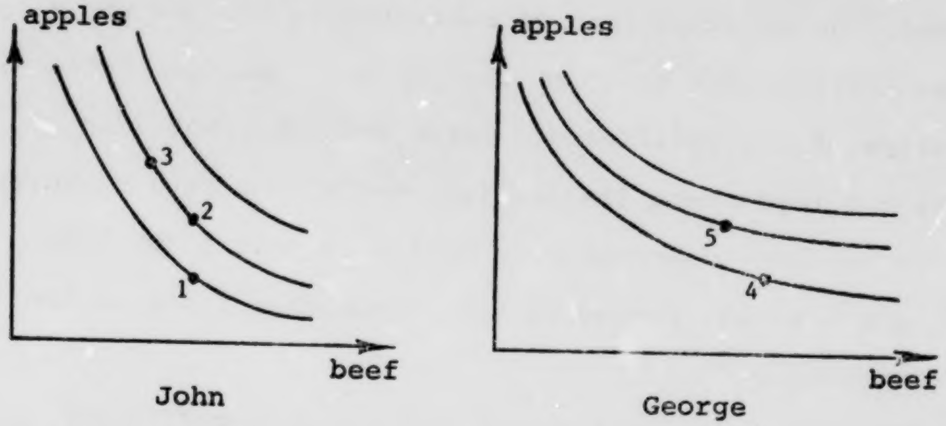
B. BASIC WELFARE ECONOMICS

Economic theorists have developed a strong justification for allocating most economic resources through free markets in which goods are traded at prices determined by competitive processes. This justification is not based on presumptions about the implicit desirability of capitalism or the institution of private property. Rather, it follows from a demonstration that the price system, together with competitive markets, leads to "economic efficiency." As defined below, economic efficiency can reasonably be considered as a desirable attribute of an economic system without regard to one's value judgments on most issues. The increasing, although somewhat begrudging, use of prices to reduce misallocation in the Soviet Union provides confirming evidence for most economists' belief that their advocacy of the price system is not ideological in nature.

The concept of economic efficiency was developed as a tool to be used to finesse the problem of weighing one man's welfare against that of another. In a strikingly deft solution to this problem, Vilfredo Pareto, in his treatise Cours d'Economie Politique published in 1897, suggested a criterion for judging the relative efficiency of alternative situations. The Pareto criterion states that: Situation A is considered to be preferable to Situation B if no one is worse off and at least one person is better off in Situation A, by their own evaluation. An allocation is then called Pareto optimal if there are no reallocations which meet the Pareto criterion. While this definition of efficiency may seem almost vacuous, it has surprisingly strong implications about the nature of an optimal allocation of resources.

It is important to note that the welfare of an individual is to be judged by the individual; paternalism is specifically rejected. In order to specify the individual's own evaluations of his welfare, the concept of a "preference map" and of the related "indifference curves" are introduced. Taking all possible combinations of all commodities (usually expressed in terms of rates of consumption), indifference curves represent the classes of commodity bundles among which a particular consumer is indifferent. If commodity bundle 1 is preferred by the consumer to commodity bundle 2, it must be on a "higher" indifference curve. For diagrammatic purposes, consider the preference structure of two individuals, John and George, in the context of just two goods, which we will think of as apples and beef. The indifference curves could then be depicted as in Figure 1.1. Since points 2 and 3 are on the same indifference curve, they represent alternative combinations of apples and beef (measured, for instance,

Figure 1.1 REPRESENTATIVE INDIFFERENCE CURVES FROM TWO PREFERENCE MAPS



in terms of pounds per week) between which John is indifferent. Since points 2 and 3 are on a higher indifference curve than point 1, they are bundles which are preferred by John to the commodity bundles represented by point 1. For reasons which we will not explore here, indifference curves are generally assumed to be shaped as those in Figure 1.1, so that the set of all bundles preferred to those on a particular indifference curve forms a convex set.

The marginal rate of substitution of one commodity for another refers to the rate at which an individual is willing to trade one commodity for another, for small changes around some point. Clearly this amounts to the condition that the individual remains on the same indifference curve, and as the small change is allowed to become infinitesimal, the marginal rate of substitution becomes the slope of the indifference curve at the point. Thus for instance, the slope of the indifference curve through point 2 in Figure 1.1 represents (in absolute terms) the rate at which John is willing to accept more apples in return for less beef, for a small change in the consumption rates of those two commodities.

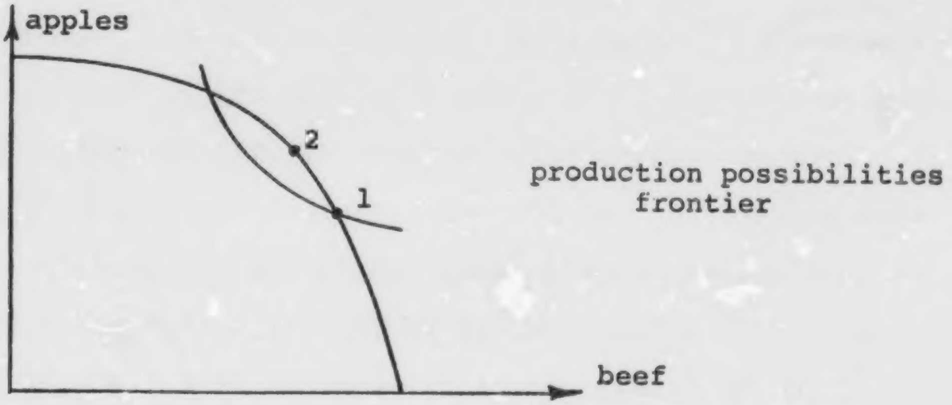
Then the first implication one can derive from the Pareto criterion is that an allocation is inefficient unless the marginal rate of substitution between any two pairs of commodities is equal for all consumers. If it is not, then it will be possible for one or more consumers to be made better off without making other consumers worse off by exchanging, or trading, goods. For example, if two consumers had different marginal rates of substitution for apples and oranges, then one would be willing to give up more apples to obtain an orange than the other would require to give up an orange. In this situation, an exchange on terms that lie in between the terms on which each is willing to trade would make both consumers better off. As long as there are differences in the marginal rates of substitution of consumers, a preferred allocation in terms of the Pareto criterion can be derived. Thus only an allocation in which the marginal rates of substitution are equal across all consumers will be Pareto optimal.

This conclusion can be illustrated in the context of Figure 1.1. Suppose, for instance, that John is at point 3 while George is at point 4. Since John's indifference curve at point 3 is steeper than George's indifference curve at point 4, it follows that George requires fewer additional apples to compensate him (that is, keep him indifferent) for the loss of a unit of beef than does John, at the margin. Thus consider points 2 and 5, which are drawn such that the same increase in beef and decrease in apples is represented by _either_ the move from point 3 to point 2 or by the move from point 5 to point 4. It then follows that a trade exists in which George gives some beef to John and John gives some apples to George which results in John's moving from point 3 to point 2 while George moves from point 4 to point 5. But points 2 and 3 are on the same indifference curve for John, so the trade makes him just as well off as before, while the trade moves George onto a higher indifference curve. Whenever such a possible trade exists, the given allocation does not meet the Pareto criterion for efficiency. But consideration of the diagrams indicates that such a trade can be found whenever the slopes of the indifference curves of two individuals are not equal; that is, whenever their marginal rates of substitution are not equal.

With exactly the same argument, one can analogously demonstrate that the marginal rate of substitution between two inputs must be equal across all firms, where the marginal rate of substitution refers in this context to the rate at which the firm can substitute one input for another at the margin while holding output constant. The third general conclusion which can be obtained from the Pareto criterion is that the marginal rate of substitution of each consumer between two commodities must equal the marginal rate of transformation between the commodities, where the latter refers to the rate at which the output of one commodity can be increased when the output of another is decreased, holding the output of all other commodities constant.

The last conclusion can be understood by superimposing the indifference curve an individual is on onto the production possibilities frontier for the commodities, where the frontier defines all combinations of the two commodities which are possible to produce, given the output level of all other commodities. In Figure 1.2 (next page) we draw the production possibilities frontier for apples and beef and superimpose an indifference curve. Suppose that society

Figure 1.2 THE PRODUCTION POSSIBILITIES FRONTIER FOR APPLES AND BEEF AND A REPRESENTATIVE INDIFFERENCE CURVE



is producing efficiently -- that is, is on the production possibilities frontier -- but the marginal rate of substitution between the two commodities is not equal to society's marginal rate of transformation. Such a situation is depicted as point 1 in Figure 1.2. Then since it is possible for society to move to a point such as point 2, this individual can clearly be moved to a higher indifference curve maintaining the consumption bundles of all other consumers. Thus, economic efficiency requires that the slope of the production possibilities frontier -- that is, the marginal rate of transformation -- be equal to the marginal rate of substitution, for each pair of goods. This last condition means that for society's resources to be allocated efficiently, each consumer must be just willing to trade goods on the same terms as society is capable of producing more of one by reducing the production of the other.

The connection between these conclusions and competitive markets is that the three general conditions, which we have argued are necessary conditions for an allocation to be Pareto optimal, would be fulfilled if resources were allocated by freely operating competitive markets in which no single consumer or firm can affect prices by his own actions. The first condition, that the marginal rate of substitution between all pairs of commodities be equal for all consumers, will be met as long as all consumers face the same prices for all commodities. Each consumer who uses his income to buy the best possible bundle of commodities, will choose a bundle for which his marginal rates of substitution equal the ratios of prices for all pairs of goods. If all consumers face the same prices, then they will all choose bundles which yield the same marginal rates of substitution. Similarly, the second condition will be met if firms face the same prices for all inputs. In their desire to minimize costs for any level of production, firms will choose combinations of inputs where the marginal rate of substitution between any two inputs is equal to the ratio of the prices of the two inputs. If all firms face the same prices for inputs, then they will all use inputs in amounts which yield the same marginal rates of substitution.

Whereas the first two conditions for Pareto optimality insure that the bundle of commodities produced by society as a whole is allocated efficiently among consumers and produced efficiently by firms, the third condition, that the marginal rate of substitution of consumers is equal to the marginal rate of transformation for any pair of goods, insures that the proper mixture of commodities is produced. This last requirement is attained by the movement of resources among industries until the value of the marginal product (the extra product which can be produced with one extra unit of some input) of each input is equalized across all industries. To see how competitive markets will ensure that this condition is met, consider an economy with two commodities, A and B, and two inputs of production, X and Y. We will use MP_X^A to denote the marginal product of X in the production of A; thus it represents the extra quantity of A which can be produced by shifting one extra unit of X into the A industry. A competitive firm will hire inputs up to the point where the value of the marginal product is equal to marginal cost; thus X will by used in the A and B industries to the point where:

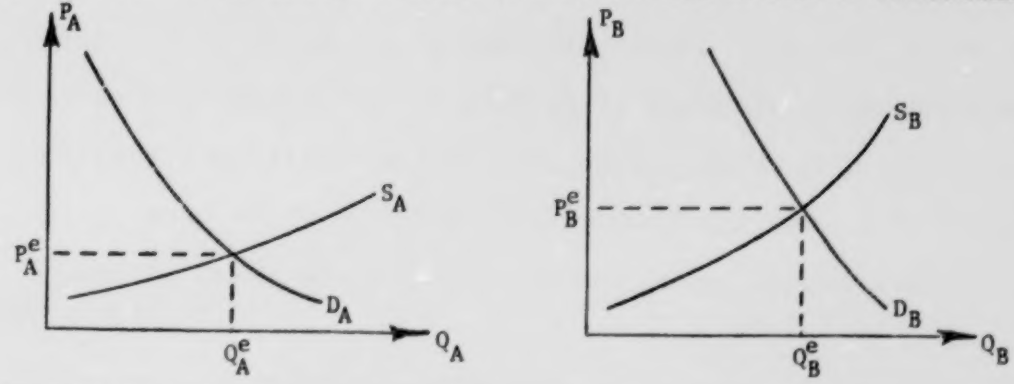
$$MC^A = P_X \Big/ MP_X^A = P_A$$

$$MC^B = P_X \Big/ MP_X^B = P_B$$

Dividing these two equations implies that the ratio of the prices of A and B is equal to the ratio of the marginal products of X in the production of B and A, which is society's marginal rate of transformation. This latter equality follows from the fact that if one unit of X is taken from the production of A and used to produce more B, the decrease in A will be MP_X^A while the increase in B will be MP_X^B .

It is useful, for the discussion which follows, to translate this last efficiency condition into terms of supply and demand. Consider the equilibrium of supply and demand in the markets for A and for B:

Figure 1.3 COMPETITIVE EQUILIBRIUM IN THE A AND B INDUSTRIES



where P_A^e and Q_A^e represent the equilibrium price and quantity for commodity A and similarly for B. Since a firm operating in a competitive industry will expand output out to the point where price equals marginal cost, the competitive supply curve for an industry indicates, for each level of industry output, the marginal cost of each producer in the industry. Since individual consumers cannot affect P_A^e and P_B^e , each consumer will purchase A and B up to a point at which the marginal rate of substitution equals the ratio P_B^e/P_A^e . Thus if the prices of the commodities are set by competition and consumers are free to buy as much or as little as they like, the marginal rate of substitution of each consumer will equal MC_B/MC_A , the ratio of the marginal costs of the two commodities, which we saw above equals the marginal rate of transformation between the two commodities. Thus determining the rate of production of different commodities by the test of whether firms can survive leads to the socially optimal mixture of outputs, and leads to the point on the production possibilities frontier which is socially efficient.

Thus far we have suggested a definition for efficiency -- Pareto optimality -- and sketched the theoretical arguments which lead to the conclusion that economic efficiency will be attained if the decisions on how much of each commodity to produce, how to produce it, and who will get to consume it are all left to the decentralized mechanisms of competitive markets. Thus, a competitive equilibrium has the economic efficiency, and we know that no change can be made in a competitive allocation which does not move at least one consumer to a lower indifference curve; in terms of the Pareto criterion, there can be no improvements over a competitive equilibrium.

It does not follow, however, that a competitive equilibrium is necessarily a good allocation, if questions of equity or fairness are considered. The competitive process simultaneously determines the prices of factor inputs, including labor of all types and all physical assets such as land, capital goods or raw materials. Thus, an income distribution is determined along with the allocation of inputs to the production of alternative output. Far from being optimal, the distribution may seem completely unreasonable to some. There are, in fact, generally an infinity of different Pareto optimal allocations, each implying a different income distribution. That is, there are many allocations of resources for which it is true that a reallocation can make some one better off only by making someone elso worse off. But, each such allocation has a different distribution of income corresponding to it. This might seem to destroy the case for allocation by competitive markets in so far as one is concerned with income distribution and dissatisfied with the resulting distribution. However, there is a converse theorem which suggests why it may still be desirable to use competitive markets. One can also prove that, under fairly general conditions, any Pareto optimal allocation can be attained as a competitive equilibrium for some particular distribution of endowments of ownership rights to assets. Thus if one is unhappy with the existing distribution of income, that "problem" can be corrected by redistribution while maintaining the efficiency properties of the competitive process.

Though it ignores some difficult technical problems, the foregoing discussion summarizes the theoretical underpinnings of the presumption, shared by most American economists, that competitive markets provide a desirable resource allocation mechanism. It follows that if the income distribution is unsatisfactory, the competitive mechanism should be retained and direct transfers of income should be employed to bring about distributional equity.

C. APPLICATIONS AND PROBLEMS

While it may not be readily apparent, these issues are directly relevant to the questions at hand. First, the basic benefit-cost methodology, which we describe below, depends crucially on the theoretical underpinnings just discussed. We are concerned here with analyzing the benefits and costs of solid waste disposal from a point of view which should, at least, have the welfare of society as a whole as the ultimate criterion. The question of how the welfare of society should be evaluated thus arises, and the Pareto criterion provides a tool by which rankings can be made which are as free from one's own political, social, and moral values as seems possible.

Consider then a government project which "takes" certain commodities as inputs, processes them in some way, and then "gives" the resulting outputs back to members of society. Assume that we have an exhaustive list of all the costs and benefits of the project. Assume also that the purpose of the project is to supply those outputs, not to redistribute income or some other purpose. How should these inputs and outputs be weighed? In particular, how can it be determined whether the overall value of the outputs is greater than the overall value of the inputs to society as a whole? The economist's answer is to weigh the outputs and inputs at their competitive market prices. The value of the project is then completely determined by the differential, if any, between the total market value of inputs and outputs. Note that in this situation the criterion used by the government is identical to that which would be used by a private firm: is the project "profitable"?

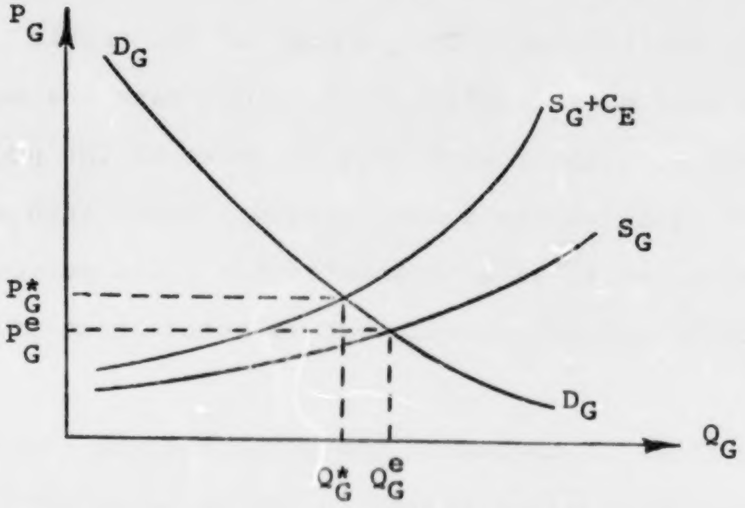
There are two classes of complications which arise which make it difficult if not impossible to use this simple benefit-cost procedure. One class of problems arises where the output is not sold in a competitive market. Indeed, the typical case is where the government is the sole producer of the commodity or commodities. In that case, the government sets the price itself, and indeed the relevant policy question becomes not just whether to produce, but also at what price and at what quantity. Furthermore, this situation in which the government is a monopolist arises not as a coincidence, but usually because the government preempts the field for some compelling reason. One such reason is the case of "economies of scale" in which higher rates of output lead to lower average cost (holding input prices fixed). In such a situation, which is often termed a "natural monopoly", it can be shown that the socially optimal level of output occurs where the price of the output is set equal to marginal cost, if it is socially optimal to produce the commodity at all. However, it is important to realize that those conclusions about the optimal output level and the optimal pricing scheme for the "natural monopoly" are derived in a context where it is assumed that the government can apply "lump sum" taxes to individuals in order to finance the deficit which such a project will necessarily incur, since marginal cost will be below average cost if average cost is falling. In order to meet the strict Pareto criterion of making everyone at least as well off as previously (when no output of this commodity was produced), it is necessary to assume that the government knows the preferences of all citizens and can cover the surplus entirely from lump sum taxes which are levied on consumers of the product who have positive "consumer surplus"; that is, who benefit by being able to buy the good in question at marginal cost rather than not having the commodity available at any price. The next chapter introduces the concept of consumer surplus more rigorously and discusses some of the complications that arise in trying to measure it.

The second class of problems which make it difficult to compute social "profit" as a guide to the desirability of a project arises when inputs are not purchased in competitive markets. Here the typical case is the appropriation of certain inputs as privately "free" goods, such as the use of clean air or water to dispose of pollutants, or the "consumption" of a quiet neighborhood by the production of noise. Historically, such inputs have been freely used by firms (and consumers), although their use has often been regulated. These are examples of what are termed "externalities", in which the production or consumption of one party affects the welfare of others through effects which are not already reflected directly through the market mechanism.

The term externality denotes the distinction between those costs imposed on society for which the firm does not pay as opposed to those which are "internalized" by the firm. Although it may seem artificial to construe external effects as the use of inputs, that interpretation provides insight. Suppose one thinks of an input, say coal, which the government decides to buy from producers and supply free to all those who request it. Obviously firms would have no incentive to use the coal efficiently. Coal would replace other fuels in many uses, and generators would be adopted which used coal wastefully but which were relatively cheap to construct. The amount of coal demanded would be constrained only by the costs of storing it and the limits of substituting it for other fuels. Firms would use it out to the point where its marginal value was zero. Such an analogy can be applied to the problems of air and water pollution and other similar externalities. Clean air can be considered an input, one which happens to appear directly in the preference structures of consumers, but can also be used as an input by firms. The input "clean air" can be substituted for filtering devices and other pollution control equipment. When firms are free to use as much clean air as they wish, without being charged for its opportunity cost, there is no mechanism to lead them to a socially optimal level of "consumption" of clean air.

This distortion in allocation can be usefully represented in the competitive equilibrium between supply and demand, where we represent the externality simply as a cost imposed on society which is in addition to the opportunity costs of the resources purchased by the industry which are reflected in the supply curve. Thus in Figure 1.4, we illustrate the competitive equilibrium for an industry which produces commodity G and which imposes external costs on society. We use C_E to represent external costs at each level of output. That is to say, $C_E(Q_G)$ is a function which indicates at each level of Q_G the extra social cost imposed for an additional unit of output which is not internalized to the firms in the industry. Thus C_E represents the difference between the industry supply curve which would result if the firms were charged for all costs resulting from their production and the existing supply curve which reflects only private costs which are internal to the firms.

Figure 1.4 THE SUPPLY AND DEMAND EQUILIBRIUM WITH AN EXTERNAL COST PRESENT

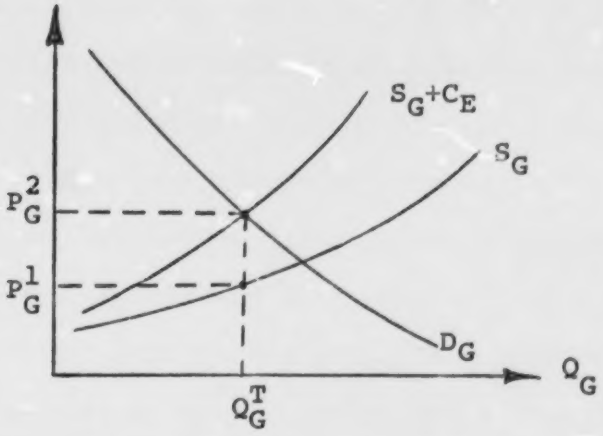


We denote the competitive equilibrium by Q^e_G and P^e_G. At the competitive equilibrium, the opportunity cost of the marginal unit of G, which is $S_G + C_E$, is higher than the value to consumers of the marginal unit.

Thus the presence of an external cost implies that the competitive equilibrium does not have the optimal properties discussed above. There are several corrective measures which have been suggested. The first, suggested by A. C. Pigou [2], is to impose a tax on those firms imposing the external cost on others, with the tax equal to the level of external cost at the margin. That is, referring to the external cost as "damage" not accounted for by market, the level of the tax would equal the marginal damage rate -- the extra damage produced by an extra unit of output -- in equilibrium. The purpose of the tax is to raise the supply curve sufficiently to generate the socially optimal level of output, by making the cost of the product to the consumer equal to its social marginal cost; such a tax is often referred to as a "Pigouvian tax", the purpose of which is not to collect revenue but to bring about efficiency.

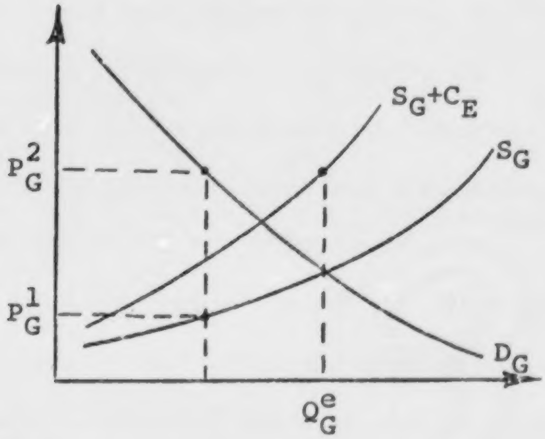
It is important to emphasize the point that the Pigouvian tax is set equal to marginal damage in the post-tax equilibrium. Consider the case where marginal damage increases as output is increased, as in Figures 1.5 and 1.6 (next page). Where a tax is imposed, we must distinguish the price paid by consumers (designated P_G^2) and that received by producers (designated P_G^1). In Figure 1.5, the imposition of a properly computed Pigouvian tax is illustrated; the level of the tax, $T = P_G^2 - P_G^1$, is equal to C_E at the equilibrium output level Q_G^T. In Figure 1.6, we illustrate the equilibrium which results when the Pigouvian tax is set equal to marginal damages C_E measured at the original, competitive equilibrium. Since C_E is assumed to be increasing, the resulting equilibrium is at an output level which is below

Figure 1.5 A PIGOUVIAN TAX SET EQUAL TO MARGINAL DAMAGE IN EQUILIBRIUM



S_G+C_E
S_G
P_G^2
P_G^1
D_G
Q_G
Q_G^T

Figure 1.6 A PIGOUVIAN TAX SET EQUAL TO MARGINAL DAMAGE IN THE ORIGINAL COMPETITIVE EQUILIBRIUM



S_G+C_E
S_G
P_G^2
P_G^1
D_G
Q_G^e

the optimal level Q_C^T and at which marginal damages are less than the imposed tax. In this case, the measurement of damages at the original competitive equilibrium rather than at the new equilibrium results in overkill; the social value of an extra unit of C is now greater than its opportunity cost. The reader can convince himself that output will be greater than the optimal level, in the case of increasing marginal damages, if the tax is set equal to average damage in equilibrium rather than equal to marginal damage. Similarly if marginal damage decreases as output is increased, the imposition of a tax equal to average damage in equilibrium will result in an output level below the socially optimal level.

There is no presumption that the receipts of a Pigouvian tax must be used to compensate those who are damaged by the production of the product. Indeed, if marginal damage is increasing, the total tax receipts will be greater than total damage (in equilibrium) while if marginal damage is decreasing, the total tax receipts will necessarily fall short of total damage. In fact, Pigou was not concerned with questions of distribution, and the notion of Pareto optimality was not yet posed when he wrote. Pigou simply noted that when all other prices are assumed fixed, the maximum social value of all output is maximized when price is set equal to social marginal cost in all industries.

Two other schemes exist for "internalizing" the external cost of some activity. The first is to make the firm legally liable for the damage imposed on others, so that those harmed can sue the firms for their damages. Note that the imposition of liability automatically provides compensation for those damaged. However, there are two significant problems. The first, obvious problem is the administrative costs which arise in the frequent situation where the damages are imposed on many -- possibly millions -- of persons while the damage to each may be rather small, particularly in comparison to the social (and private) costs of adjudicating the claim. Second, legal procedures may be too inflexible to provide an appropriate response where the marginal damage produced by the output of each firm does not add up to the total damage incurred. That is to say, consider the case where marginal damage increases. In that case, the damage imposed by the activity of a particular firm is less, the smaller the production of other firms. Legal thinkers may accept the defense that "our firm cannot be held legally liable for the extra damage it imposes since such damage arises only because of the activities of other firms". While it is true that the movement to the optimal output level requires that each firm should be treated as the "marginal firm", as the Pigouvian tax implicitly does, this notion undoubtably contradicts what seems to be common sense.

The third reorganization which accomplishes the objective of attaining an efficient allocation of resources is to bring the production resources of the offending industry (or firm) and those assets of the parties damaged under common ownership. If the external cost is based on a local effect of some sort, for instance, the joint ownership of the land on which the offending activity takes place and that on which the damage occurs will automatically lead the owner to restrict the offending activity to its optimal level. The reason, of course, is that the damage is automatically "internalized". While joint ownership may be an effective solution to some cases of external costs, it is also a useful device for purposes of analysis. For instance, Baxter and Altree [1], provide considerable insight into the problem of optimally controlling airport noise by repeatedly asking "what would a joint owner of the airport and of the surrounding land affected by the noise do?" Clearly such a solution may produce problems of local land monopolization and problems of inefficient land management, produced by insufficient specialization, in most cases. Furthermore, such a solution would not be politically feasible in general, since it would typically necessitate increasingly centralized control of land use. Nevertheless, joint ownership should be recognized as a possible solution for extreme cases.

D. SOLID WASTE MANAGEMENT

It will be quite instructive to see how the solution of joint ownership would work in the solid waste context. Let us assume that the externalities associated with landfills extend only within a specified area of reasonable size (this may not be appropriate when the externalities associated with transportation to and from the landfill are considered). Suppose that all the land within that area were purchased, at market value, from its owners before the possibility of a nearby landfill became apparent (also, before the possibility of profits from a government land acquisitition became apparent). That is, the land value would have to be determined in the absence of any affect from the prospect of government action.

Suppose, then, that all of the land were transferred to a "sanitary landfill authority." Suppose that this authority were to be paid for disposing of solid waste, the payment coming from the municipality, and representing the opportunity cost to the municipality of otherwise disposing of the solid waste; that is, the total cost to the municipality of disposing of the solid waste in the next best alternative. Suppose the municipality were then told to operate as if it were a private firm, with an objective of maximizing the value of the firm's assets, namely its holdings of land. The value of each parcel of land is equal to the present discounted value of its potential rents in all future periods.

In deciding how much waste to accept -- and whether to accept it at all -- the authority would be led to consider the effect of using part of the land for a landfill on the value of the surrounding land. Given the assumptions that the external costs are contained within the region owned by the authority, and also the assumption that all external costs are perceived and understood by potential users of the land, the possible decrease in rents in the surrounding land provides a precise evaluation of these external costs. The rental value of the adjoining land thus reflects the social evaluation of the external costs for a particular year; the authority must weigh the possible decreases in rent over all time. This is accomplished by considering the discounted value of rents, which is precisely the market value of the land.

The conceptual scheme by which the authority would arrive at the optimal use of the land and the optimal size and design of a landfill on part of the land would then be the following. The authority would announce a proposed plan for the use of part of the land as a landfill. The proposed plan would include plans to "buy" a certain amount of solid waste from the municipality for each year until the landfill site were exhausted. The payments for "purchasing" the solid waste would then represent revenues for the authority; direct costs of disposal, such as equipment and labor costs, would be subtracted from these revenues to give yearly net "profit". These "profits" would then be discounted back to the present using the applicable rate of interest (the correct computation of which will not be discussed here). If there were no external costs to be considered, this would complete the conceptual scheme. The municipality could set up many different authorities, giving each the mandate to maximize the "value" of the authority -- namely, the present discounted value of its net receipts -- and letting the various authorities bid on the solid waste to be disposed.

However, since there may be external costs, which may decrease the value of the land adjoining the landfills, these costs must also be considered in arriving at a socially optimal system for solid waste disposal. Within the scheme suggested above, however, this can be accomplished very simply. The authority must look not simply at the value of the land to be used as a landfill but also at the value of the surrounding land which is affected by the landfill. Thus, any decrease in the value of the surrounding land must be subtracted from the "present value of the authority" to arrive at the net value of the authority. Of course, if the landfill were to increase the value of surrounding land, this would be added to the authority's balance sheet.

Within the assumptions mentioned, an authority which maximized the total value of the land it controls would naturally choose the plan which was socially optimal. This is predicated, of course, on the assumption that the "price" it receives to dispose of solid waste reflects the opportunity cost of disposing of the solid waste by some other means, either by another authority or in some other fashion. If that price is appropriate, however, the decisions of the authority would be socially optimal. If the "net profits" from the landfill activity were not positive at that price, it would be a signal that this landfill site should not be used at all, and a profit maximizing authority would choose not to accept any solid waste. If profit from the landfill activity were positive but were not large enough to balance the losses the authority would experience on the "land holding" activity, this would correspondingly signal that from the social point of view, the landfill site should not be used. If, however, the landfill site should be used intensively because the next best alternatives have very high opportunity costs, the authority would naturally be led to increase its landfill activity in the face of a "high price" for disposing of solid waste.

The viability of such a scheme depends very crucially on the assumption that such an authority would work efficiently and would be capable of predicting the effect of the landfill activities on the present and future rental value of the surrounding land, of course. It also assumes that by simply establishing such an authority with the mandate to maximize the value of all of its land, an organization would arise which would actually pursue that objective and not be diverted to an alternative objective dictated by bureaucratic forces. Nevertheless, the significant point is that our conceptualized authority would make socially optimal decisions if it pursued the wealth maximization objective. This provides the standard by which to evaluate the plan of an actual municipality.

The crucial aspect of our conceptual authority, of course, is that the external costs have been "internalized" by giving the authority the ownership of all adjoining land which is affected by the landfill activity. If such a scheme is infeasible, the socially optimal method of deciding how and where to dispose of solid waste is to mimic the behavior of such an authority. Since such an authority "pays" for all of its "inputs", the efficiency criteria described above are automatically met.

In order for a municipality to duplicate the decisions of such an authority, it must be able to predict the effects on surrounding land values of the landfill activities. This report is directed toward advancing the state of the art in that area. Of course, the conclusion that changes in land values provide an appropriate index of external costs depends on a series of assumptions, some of which appear partially invalid. Thus we also consider direct methods of evaluating such external costs in the next four chapters.

A proper benefit-cost analysis of a municipal project such as a sanitary landfill must include external costs in the costs of the project. However, it must be emphasized that simply including such external costs does not mean that the project will meet the strict Pareto criterion. If the benefit-cost ratio is greater than 1 with the inclusion of all costs and benefits, it means that there is a conceptually feasible tax scheme to pay for the project and to compensate all those who bear costs of the project which will insure that all members of society are better off with the project than without. However, the standard benefit-cost analysis blatantly adds costs and benefits across different citizens.

A cost to one citizen and an equal benefit to another are assumed to "cancel out," whereas the strict Pareto criterion does not allow these two effects to be compared.

In this introductory chapter, we have provided a superficial introduction to the theoretical basis of benefit-cost analysis and to the treatment of external costs. The next chapter analyzes several of the crucial theoretical questions in more detail and with greater rigor.

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CHAPTER II

MEASURING EXTERNALITIES IN THEORY

A. INTRODUCTION

This chapter surveys and evaluates various approaches to the measurement and valuation of external effects. The chapter deals primarily with the problem of defining an ideal measure and discusses some of the problems which can arise when one attempts to obtain estimates of the proposed measures. Empirical work on the measurement of externalities is discussed in Chapter III.

An externality can be defined as follows. Let W^i, the welfare or production variable of the ith unit in the economy, be given by the welfare (production) function

$$W^i = f^i(x^1, \ldots, x^j, \ldots, x^N, z^1, \ldots, z^j, \ldots, z^M)$$

where $x^j = x^j_1, \ldots, x^j_K$ is the consumption bundle which is under the control of the jth consumer and $z^j = z^j_1, \ldots, z^j_L$ is the input bundle which is under the control of the jth production unit. Then the jth unit's consumption of commodity k (or use of input k) imposes an externality on unit i if and only if

$$\frac{\Delta W^i}{\Delta x^j_i} \neq 0, \quad \text{or} \quad \frac{\Delta W^i}{\Delta z^j_k} \neq 0.$$

In words, unit j imposes an externality on unit i if and only if a change in a variable under the control of unit j (commodity or production input) results in a change in unit i's utility or output level.

The above definition is formulated in terms of finite differences since a small (marginal) change in a variable under the control of unit j may not have an effect on unit i, while larger discrete (inframarginal) changes may have an effect. A good discussion of this and related issues in the definition of externality can be found in Buchanan and Stubblebine [9] and Arrow [2].

This chapter will thus be concerned with theoretical issues that arise when one tries to value changes in W^i which are attributable to changes in a x^j_k or z^j_k.

Approaches to the Valuation of External Effects

A number of approaches to the valuation of externalities have been used or suggested since the problems encountered vary with the type, source, and location of the external effect being considered. No one approach appears to be best in all situations. Two general approaches are discussed in this chapter. In Section B we consider the possibility of obtaining more or less direct valuations of external effects based on individuals' willingness to pay for the elimination or prevention of an external effect. A distinct disadvantage of the direct measurement approach is that it requires more information than is available in most cases where external effects are present. In particular, market prices, or some good approximations thereof, are required. Such prices are, however, extremely difficult to obtain for most externalities associated with solid waste disposal activities. The theoretical considerations which lead to this information problem are discussed in Section C.

Where externalities are associated with particular sites or locations, as is the case with solid waste disposal activities, it may, however, be possible to infer measures of willingness to pay for the removal of most of the externalities associated with a particular activity in a somewhat less direct manner from differences in equilibrium land rents between two sites identical in every respect except the activity. This approach to measurement is discussed in Section D.

Criteria for Ideal Measures of External Effects

Since, as will be shown in Section B, it is in general possible to define individual willingness to pay for a particular action in a large number of ways, we devote the remainder of this section to a discussion of criteria which can be used to evaluate the desirability and usefulness of alternative definitions. Such criteria are useful since there may be more agreement among economists on the appropriateness of certain criteria than on the usefulness of any one particular definition.* This approach has recently been used by both Harberger [23] and Mohring [42] to defend particular measures of willingness to pay.

Harberger [23, p.785] suggests that economic measurements be based on the following set of postulates:

(a) the competitive demand price for a particular unit of any commodity measures the value of that unit to the demander;

(b) the competitive supply price for a particular unit of any commodity measures the value of that unit to the supplier;

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*It is, of course, possible that no definition or measure exists which satisfies a given set of criteria, or that a large number of measures satisfy the criteria.

(c) when evaluating the net benefits or costs of a given action (project, program, or policy), the costs and benefits accruing to each member of the relevant group (e.g., a nation) should normally be added without regard to the individual(s) to whom they accrue.

These postulates can be rationalized as follows. The first two postulates are based on the efficiency of market allocations under competitive conditions, which was discussed in Chapter I. Measurements based on these postulates would thus extend hypothetical competitive market valuation to non-market activities. It can thus be argued that the resulting allocation of resources will be efficient since the attributes of the competitive market mechanism are extended to the non-market activity (e.g., the marginal benefits of the activity are equated with its marginal costs). It should be noted, however, that if imperfections exist in the market sector second best issues may arise (e.g., equating marginal costs to marginal benefits in the non-market sector does not assure efficiency). This issue is discussed in greater detail in Section B. The third postulate involves a distributional value judgment and cannot be evaluated on purely scientific grounds.* It can, however, be interpreted as representing a politically approved value judgment in the U.S., since the Congress in the Flood Control Act of 1936 required that projects be undertaken if and only if "the benefits to whomsoever they may accrue [are] in excess of the estimated costs." (Quoted in Marglin [34, p.16]).

Harberger uses these postulates to defend measures of welfare effects (effects of activities which distort resource allocation) based on Marshallian consumers surplus, which we define below. These postulates do not, however, define a unique measure of welfare effects since they may be consistent with more than one measure if prices change due to the activity whose effect we are attempting to evaluate. This, of course, is a problem with all measures based on consumers surplus and is discussed in detail in Section B. It may also be difficult to evaluate measures which are not based directly on market valuations, such as measures based on differences in land rents or direct surveys of willingness to pay, with these postulates. The first two postulates appear to be directed at restricting the techniques used to construct a particular measure, rather than restricting the properties an acceptable measure may possess.

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*It should also be noted that properties of welfare measures which hold for the individual need not, and in fact do not, hold when summed, or aggregated in some other manner, over individuals. This issue is discussed in greater detail at the end of Section B.

A more general set of criteria, without these shortcomings, has been suggested by Mohring [42, p.349]. He would require:*

(1) If an economic activity results in several effects (say externalities) the measured change in welfare attributed to the activity should be independent of the order in which the effects are regarded as having occured.

(2) The maximization of net benefits from an activity, including measured external benefits and costs, should yield necessary conditions which are consistent with Pareto Optimal resource allocations.

(3) In comparing the value of two alternative activities, say A and B, to an individual the measure should value A more highly than B if and only if the individual prefers A to B.

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*Mohring is concerned primarily with the welfare effects of price changes and taxes. We have therefore modified his language to include other welfare effects. This does not materially modify the criteria, however, since most welfare effects can be interpreted as a change in the price of some appropriately defined commodity.

(4) In aggregating the measure over individuals, the weights attached to individuals should depend only on their utility levels, and not on their incomes and the market prices which they face.

The first criterion assures that a unique measure will be assigned to any activity generating several external effects. The second criterion ensures that the measure will embody information relevant to efficient (in the sense discussed in Chapter I) decision making by a policy maker. Criterion (3) ensures the Pareto Optimality of decisions involving discrete or distinct alternatives. For example, if the measure assigns values to alternatives A and B relative to a third alternative C, the measure should assign a higher value to A if and only if A is preferred to B. Most conceptual measures of welfare effects are defined with respect to particular individuals. Reaching a decision about a particular activity will in general require some form of aggregation of such measures for the affected group. Only if such aggregates satisfy Criterion (4), and if individual preferences satisfy some additional restrictions, is it possible to state that an increase in aggregate measured welfare also implies an increase in a well defined, individualistic, social welfare function. This issue is discussed in greater detail in Section B. The conditions and Criterion (4) turn out to be extremely restrictive, implying a lack of generality in commonly used measures of welfare effects.

Which criteria are most important must, however, be determined by the judgment of the user of the welfare measure, and the context in which it is to be applied. The criteria do, however, provide a set of standards against which alternative measures can be judged, and should aid in eliminating "weak" measures. The situation is similar to that encountered by producers of index numbers. An "ideal" index does not in general exist. Alternative indices are therefore judged on how well they perform relative to a limited set of criteria.

B. WILLINGNESS TO PAY: TRADITIONAL APPROACHES TO THE MEASUREMENT OF WELFARE CHANGES.

Economists have been concerned with the problem of valuing economic activities for which no market exists, and the closely related problem of valuing the welfare gain (or loss) a consumer obtains when he is given the opportunity to purchase some commodity at a lower (or higher) price than some reference price, since the middle of the 19th century.* In this section we discuss this literature and its relevance to the problem of valuing externalities associated with an economic activity. We consider first the problem of estimating welfare costs or gains associated with price changes. We then discuss the relevance of this problem to the measurement of external effects.

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*A problem of this type was first discussed by Depuit [16] in 1844. He suggested the use of a consumer's surplus

Measuring the Effect of Price Changes on Individual Welfare

The typical problem addressed in this literature can be stated as follows: What is the welfare gain or loss to an individual when the price of a commodity, say commodity x, changes from p_x to p'_x? This problem is of general interest since a broad range of economic changes can be analyzed in this framework. For example, what is the welfare cost of an excise tax on commodity x? Or what is the social value of a new bridge for which no tolls are charged? (The price of its services may be considered to be arbitrarily large before it is opened and to be zero afterward.)

The problems inherent in assigning a value to the changes considered above can be readily illustrated using indifference curve analysis. Assume we are given a consumer

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measure as a means of determining the social value of the services of a bridge. After Depuit the problem did not, however, receive further notice until the more recent work of Marshall [36] and Hotelling [2

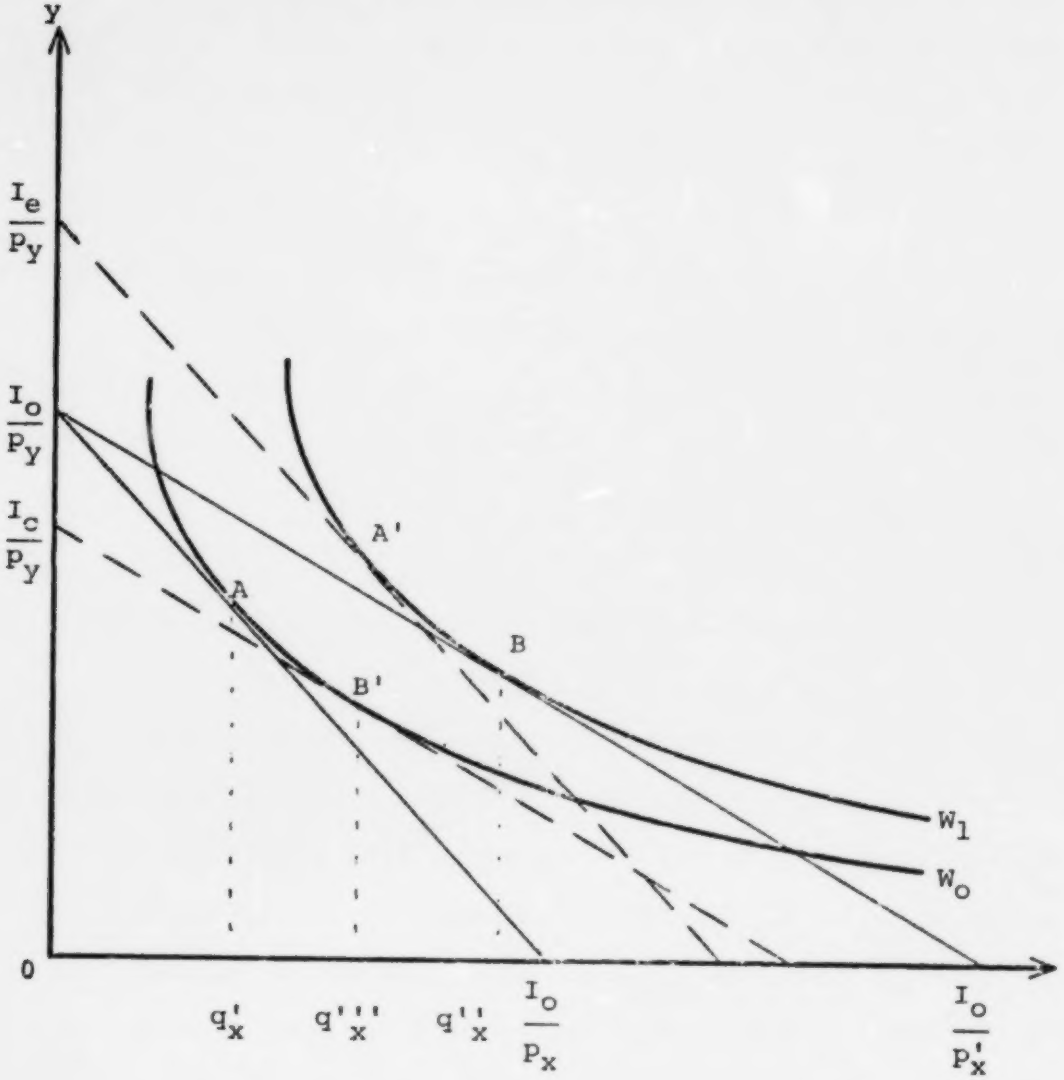
y
$\frac{I_e}{P_y}$
$\frac{I_o}{P_y}$
$\frac{I_c}{P_y}$
A'
A
B
B'
W_1
W_o
0
x
q'_x
q'''_x
q''_x
$\frac{I_o}{P_x}$
$\frac{I_o}{P'_x}$

Figure 2.1 COMPENSATING VARIATION AND EQUIVALENT VARIATION MEASURES OF THE BENEFITS FROM A REDUCTION IN THE PRICE OF x

who has a money income of I which he can use to purchase two goods, x and y. The consumer's budget constraint, expressed in terms of good y, is thus given by

$$q_y = I/p_y - p_x/p_y \cdot q_x$$

where q_x and q_y are the quantities of x and y respectively. The consumer's utility is assumed to be given by the (quasi concave) utility function

$$W = W(q_x, q_y).$$

The consumer's budget constraint is given, for relative prices $P = p_x/p_y$ and money income I_o, by the line $I_o/p_y \ \ I_o/p_x$ in Figure 1. If the consumer maximizes his utility subject to this budget constraint he will be in equilibrium at point A. At point A we can assign an arbitrary number, W_o, to the consumer's utility or welfare. This level is constant along the curve labeled W_o by the definition of indifference curves. Now suppose that the consumer is given the opportunity to purchase x at a lower price, $p'_x/p_y = P'$. His budget constraint is now given by the line $I_o/p_y \ \ I_o/p'_x$, and there is a new equilibrium at B with a new welfare level, to which we can assign any arbitrary number $W_1 > W_o$. Since the choice of W_o and W_1 is inherently arbitrary, so is their difference. A measure of the change in welfare based on the difference $W_1 - W_o$ would thus have little meaning. We must employ instead some meaningful unit of measurement, such as units of y or money income.

There are, however, a large number of ways in which a dollar value can be assigned to this change in welfare. The "conventional" approach, first suggested by Depuit [16] and Marshall [36], is to use the change in consumer's surplus attributable to the price change. Depuit measured consumer's surplus by the relevant area under the consumer's ordinary demand curve. Marshall's measure has been given a similar interpretation. There is, however, controversy about his interpretation (see, for example Hicks [26] and Patinkin [47]). The relationship between areas under demand curves and measures of willingness to pay is discussed in greater detail below.

Much of the recent theoretical discussion of welfare measures has, however, centered on two definitions which were suggested by Hicks [27]. (A more recent and extensive discussion is given in Hicks [26]). The measures are:

(1) The compensating variation, defined as the

maximum amount of money that the consumer would be willing to pay in his initial position for the opportunity of purchasing commodity x at relative price P'.

(2) The equivalent variation, defined as the minimum amount of money the consumer would be willing to accept, after the price has been changed, as compensation for returning to the original price.*

The compensating variation is given by $I_o - I_c$ in Figure 1, since with an income of I_c and relative price P' the consumer will be in equilibrium at B' on indifference curve W . The consumer is thus indifferent between facing the relative price P with income I_o and facing the relative price P' with income I_c. He is therefore willing to pay $I_o - I_c$ for the privilege of facing prices P'.

The equivalent variation is given by $I_e - I_o$ in Figure 1, since the consumer would require an income of I_e

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*These two definitions of willingness to pay can also be defined in terms of a consumer's indirect utility function (which gives a consumer's utility in terms of his income and the vector of prices he faces). Let U(I,P) give the maximum utility the consumer receives when he has money income of I and faces a price vector P. Then, the compensating variation measure of willingness to pay is given by the quantity CV which satisfies $U(I-CV,P') = U(I,P)$, where P is the initial price vector and P' is the price vector which prevails after the effect, which we are trying to measure, has occurred. Similarly, the equivalent variation measure is equal to the quantity EV which satisfies $U(I,P') = U(I+EV,P)$.

with prices P to reach a point, A', at which he is at least as well off as he was with income I_c and prices P'.

Unfortunately, the compensating variation measure of any change in welfare will not in general equal the equivalent variation measure of the same change. The reason is that the respective variations are calculated for two different relative prices for x and y. One can define willingness to pay for a change in economic conditions which change an individual's welfare with respect to any arbitrary set of relative prices; Hicks merely selected two sets of prices at which the changes were valued. This implies that willingness to pay can be defined in an infinite number of ways, one for each relative price, each of which may assign a different monetary value to the welfare change. Criteria, such as those discussed in Section A, are therefore required for the selection of "good" measures from this large number of potential measures.

It has been argued that in any specific application, only one measure of willingness to pay will be relevant (see Henderson [25]). For example, if in Figure 1 we want to know how much an individual with an initial welfare level of W_o and income of I_o would be willing to pay for a change which resulted in a new equilibrium price ratio of P', only the compensating variation measure is relevant. Mishan [40] has suggested that only the compensating variation and equivalent variation measures are relevant. Patinkin [47] points out, however, that this argument assumes that the consumer faces a linear budget constraint, as in the case when prices are determined in competitive markets. However, if the consumer buys from a discriminating monopolist, the relative prices he faces will no longer be independent of his consumption choice, making other measures of welfare change relevant.

If the competitive pricing assumption does hold, the compensating variation (or, equivalent variation) measure has several attractive properties. It is based on intuitive notions of willingness to pay. It is consistent with Harberger's first two postulates and Mohring's first three criteria. The compensating variation can also be related to the compensated demand curve for x, constructed by adjusting the consumer's income so as to keep his welfare constant at its level before the price change. This compensated demand curve is shown in Figure 2 by $D_o D'_o$. It can be derived from the indifference curve analysis of Figure 1 as follows. With an income of I_o and relative price P, the consumer maximizes his welfare at A in Figure 1. This equilibrium is shown as point a in Figure 2.

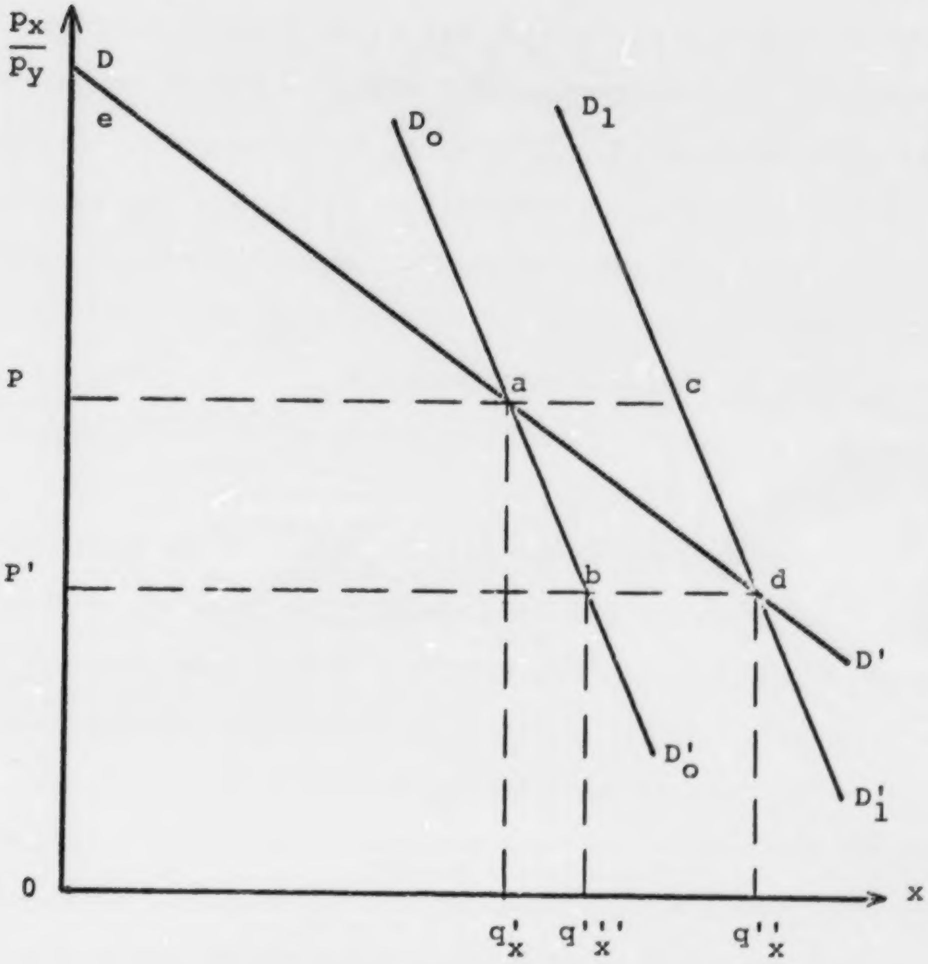

Figure 2.2 DEMAND CURVES AND MEASURES OF THE BENEFITS OF A REDUCTION IN THE PRICE OF x.

When the relative price of x is reduced to P', the consumer can increase his welfare by increasing his consumption of x from q'_x to q''_x. This new welfare maximum is shown as point B in Figure 1 and d in Figure 2. By considering the consumer's consumption of x at all other relative prices for x in a similar manner, the ordinary demand curve, DD', for x can be derived. If, as the price changes, income is adjusted to keep his welfare at level W_o, the resultant demands trace out the consumer's compensated demand curve, $D_oD'_o$. Thus if the price of x is reduced to P' and income is lowered to I_c (to keep welfare at W_o), an equilibrium consumption q'''_x results. This is shown as point B' in Figure 1 and point b in Figure 2.

It can be shown that the compensating variation, I_o-I_c, is given by the area under this compensated demand curve between the prices P and P' (see Patinkin [47, pp. 87, 88] for a detailed derivation of this result). This result can be intuitively motivated as follows. The demand curve $D_oD'_o$ can be interpreted as a function relating the consumer's willingness to pay for marginal units of x to his consumption of x (when his income is adjusted so as to keep his welfare constant at level W). Therefore, the area under the demand curve up to q'_x, for example, represents the consumer's total willingness to pay for q'_x units of x (area

$Oq'_x ae$ in Figure 2). The difference between what the consumer actually pays, i.e., the area under the price line from O to q'_x (area $OPaq'_x$ in Figure 2) and his total willingness to pay is thus a measure of what the consumer would be willing to pay for the privilege of purchasing x at price P when his welfare is maintained at W_o. This difference increases by the amount P'Pab when the relative price at which x may by purchased is reduced to P'. The consumer would thus be willing to pay at most an amount equal to area P'Pab for the privilege of buying x at relative price P' rather than P, if his welfare is held constant at W_o. This, of course, is the definition of a compensating variation.

Likewise, we can construct through point d in Figure 2 the compensated demand curve, $D_1 D'_1$, which holds constant the consumer's welfare at level W_1, the welfare level the consumer attains when he maximizes his welfare after the price change. Since $D_1 D'_1$ can be given an interpretation analogous to that given $D_o D'_o$, areas under this curve are measures of the consumer's willingness to pay for x when his welfare is held constant at W_1. Area P'Pcd thus represents the minimum compensation a consumer would demand for returning to P, after the price had changed to P'. This is, of course, the equivalent variation measure of of the welfare change.

The "conventional" measure of the welfare change is given by the change in the (Marshallian) consumer's surplus, area P'Pad. The conventional measure of the welfare change corresponding to a decrease in the price of x thus exceeds the compensating variation measure, but is less than the equivalent variation measure, if x is a normal good. (In the case of a price increase, the conventional measure is less than compensating variation and greater than the equivalent variation.)

An important result of Hicks [26] is the proposition that if the demand for x is independent of income (i.e., if the income elasticity of x is equal to zero, implying that there are no income effects when prices change), the compensating variation measure, the equivalent variation measure, and the Marshallian consumer's surplus measure are identical. To see this, consider the reduction in the relative price of x from P to P' in Figure 2. This change results in a movement from a to d along the ordinary demand curve, D D'. We then adjust the consumer's income, so as to maintain his welfare at level W_o, in order to get a point on the compensated demand curve. This adjustment in income will not, however, alter the consumer's consumption of x, if his demand for x is income inelastic. Point d is therefore also on the compensated demand curve. The ordinary demand curve thus coincides with the compensated demand curves in this case. It follows that welfare measures which are based on areas under these curves will also coincide.

Thus, if income effects in the demand for x can reasonably be ignored, willingness to pay for welfare changes can readily be computed from the areas under ordinary demand curves. Such demand curves can be estimated, in principle, from observable price and quantity information.* In cases where income effects are present, the determination of a consumer's willingness to pay is more difficult since it requires knowledge of the consumer's preferences at consumption levels which are not ususally observed (i.e., the shape of the indifference curve between points A' and B, and A and B' in Figure 1), or knowledge of the consumer's compensated demand curve. A possible approach in this case would be to postulate a particular form of the utility function and to estimate the parameters of this function, thereby obtaining estimates of the income effects (see Mohring [42] for a discussion of this possibility). This approach appears to require, however, either very restrictive assumptions about consumer preferences, or more data than is usually readily observable.

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*It should be emphasized that we are dealing with individual demand curves here. The use of market demand curves involves aggregation problems, which are discussed at the end of this section.

It is thus apparent that willingness to pay for a change in prices cannot be sensibly defined in terms of observable economic variables except in very special cases. How it should be defined must depend both on the specific use to which the measure is put, and on the conditions facing the consumer whose willingness to pay we are attempting to estimate. Only if competitive conditions prevail and income effects are absent will the Marshallian measure, based on areas under the ordinary demand curve, yield unique measures of willingness to pay from readily observable data.*

Measuring the Effect of Externalities on Individual Welfare

We consider next the special problems one encounters when one attempts to measure and value external costs.

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*Welfare measures based on the Marshallian and other measures of consumer's surplus have, however, been broadly applied in spite of these conceptual difficulties. Applications include studies of the welfare effects of various taxes (see Harberger [21, 22] for example), and the measurement of benefits from government programs (see Prest and Turvey [49] and the articles in Dorfman [17] for example). Numerous other applications of consumers surplus to the measurement of other types of distortion, such as tariffs and monopoly, are surveyed by Currie, Martin, Murphy and Schmitz [12].

These problems can be readily analyzed in the framework which we developed above if the externalities are defined appropriately. In most cases, an external "bad" can be considered the absence or unavailability of a commodity which the consumer desires. For example, if a burning dump pollutes a neighborhood, the residents of the neighborhood experience a lack of clean air. Thus the residents' willingness to pay for clean air, given the current level of air pollution, provides a measure of the external costs of the pollution. In general, we assume:

$$\begin{bmatrix}\text{EXTERNAL COSTS TO}\\ \text{INDIVIDUAL i OF}\\ \text{ACTIVITY j}\end{bmatrix} = \begin{bmatrix}\text{EXTERNAL BENEFITS RECEIVED}\\ \text{BY THE INDIVIDUAL WHEN}\\ \text{ACTIVITY j IS CURTAILED}\end{bmatrix}.$$

For example, in terms of Figure 1, a movement from, say B to A would represent a cost to the individual. A movement from A to B would therefore be defined as the corresponding benefit. Our problem is to place a monetary value on the difference between situations A and B. This value should ideally be the same whether we view the difference as a cost (moving from B to A) or a benefit (moving from A to B).

Let us now carry the analogy to market commodities a step further. When air pollution exists, clean air is available to the residents only at a positive price. On the other hand, if the pollution is eliminated, clean air becomes available at a price of zero. The problem of estimating the external costs of, say, pollution, can thus be formulated in the same framework as the one used to measure the welfare effects of price changes.

This conceptual approach to the measurement of external effects is illustrated in Figure 3, which shows the opportunities and preferences of an individual who is affected by an externality, say air pollution. The individual's dollar consumption is shown on the vertical axis and the level of pollution on the horizontal axis. We assume the consumer's initial income is equal to OI_o and that the initial level of pollution is equal to OE_o. The consumer is thus initially at point A in consumption-pollution space on indifference curve W_o. The indifference curves slope downward to the left since air pollution is considered a "bad" rather than a "good". The good which we are really considering in this case is clean air which increases to the left from E_o. Thus, for example, point E_2 would represent a mixture of air consisting of 50% air polluted at level E_o and 50% clean air.

We assume the individual purchases the mixture of

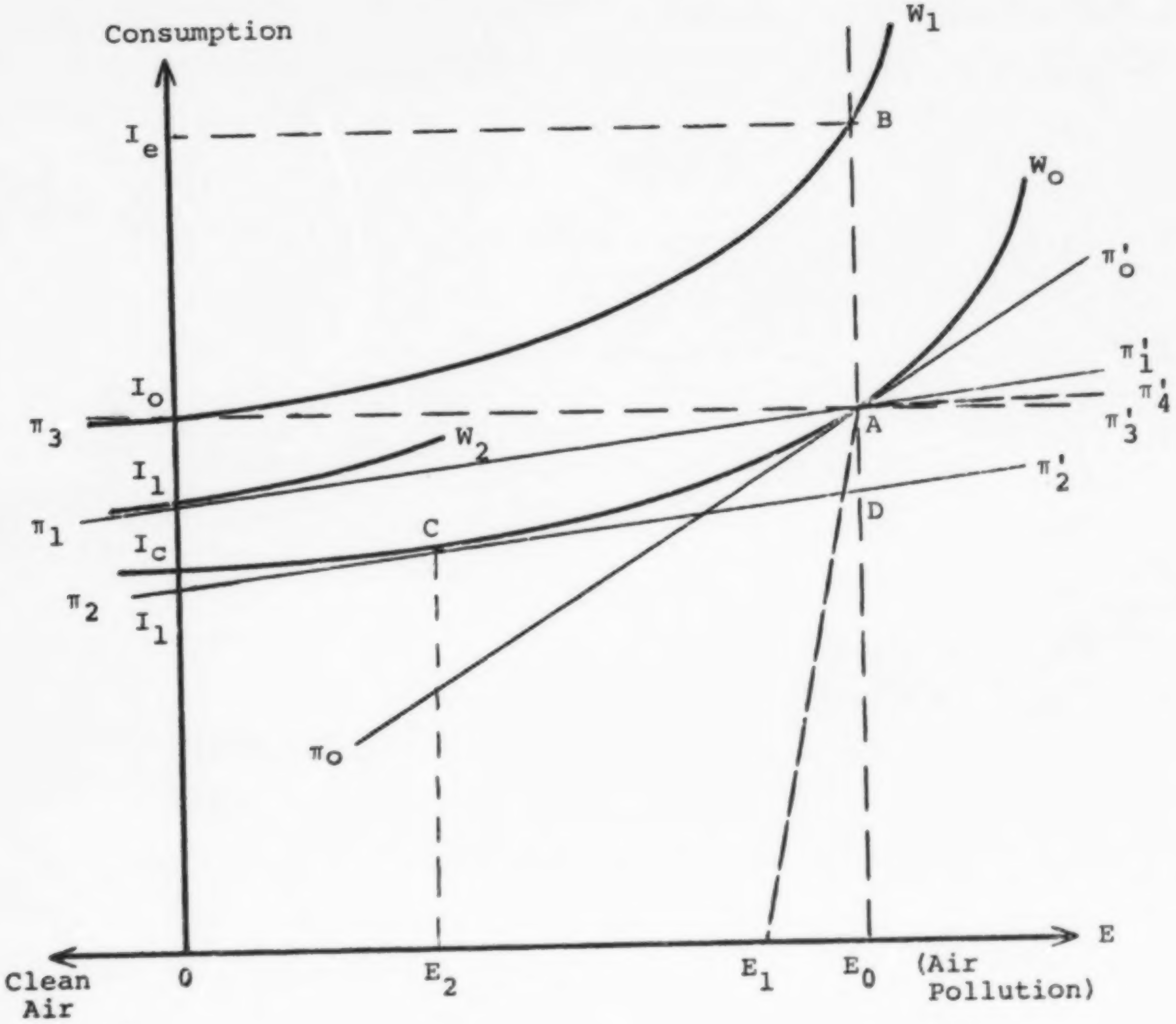
Consumption
W_1
I_e
B
W_o
π'_o
I_o
π'_1
π'_4
π_3
A
π'_3
W_2
I_1
π'_2
D
π_1
C
I_c
π_2
I_1
π_o
E
Clean Air
0
E_2
E_1
E_0
(Air Pollution)

Figure 2.3 COMPENSATIONAL VARIATION AND EQUIVALENT VARIATION MEASURES OF THE BENEFITS OF A REDUCTION IN AIR POLLUTION CONTROL

clean air and other consumption goods which maximizes his welfare subject to his budget constraint. His budget constraint is, however, unusual in that one would expect it to have a kink at point A. Consider first the possibilities for purchasing clean air. In general, the most efficient point to stop air pollution is at the source. For any one individual this is, however, likely to be extremely costly. Therefore, we represent the individual's budget line for purchases of clean air by AE_1 in Figure 3. The individual cannot, however, readily sell clean air at any positive price (i.e., receive payment for accepting higher levels of pollution), given present institutional and technological conditions. Thus, the individual's market opportunities for voluntarily accepting higher levels of pollution would typically be given by a budget line such as $A\pi_4'$.

It should be remarked that the two segments of the budget constraint shown in Figure 3 need not be linear since there are no markets in which clean air can be traded at a constant price. For example, a one per cent reduction in pollution from level E_o may be cheaper at point E_o than at point E_1 or E_2. This does not, however, effect the analysis which follows since it requires only that a kink exist at point A.

The situation in which all pollution is eliminated at zero cost to the pollutee is represented by point I_o in Figure 3. At this point the individual is on indifference curve W_1. The consumer's loss in welfare from pollution is thus given by the difference between indifference curves W_1 and W_o. As was the case with the welfare effects of price changes, there are many ways in which this difference can be measured in money terms. However, in any specific application, one particular measure will usually be indicated. In the present case, two measures are of particular interest.

One measure, which is particularly relevant when the elimination of external effect is being considered, is the maximum amount the individual would be willing to pay for the elimination of the pollution. If the pollution is to be eliminated at zero cost to the consumer (the price of clean air falls to zero), the maximum amount he would be willing to pay is $I_o - I_c$, since with income I_c he would be indifferent between living without pollution and living with pollution OE_o and income I_o.

This measure is related to the compensating variation measure discussed above. It should be noted, however, that the area under the compensated demand curve for clean air, derived by holding welfare constant along indifference curve W_o, no longer is necessarily a measure of the compensating variation. This can be seen more readily if we decompose the elimination of pollution into two steps. First assume that the consumer is confronted by a price for clean air just low enough so that he would purchase enough clean air to eliminate all air pollution (represented by $\pi_1\pi_1'$ in Figure 3). The income of the consumer measured in terms of consumption is thus I_1 after the price reduction. The compensating variation measure of the improvement in welfare experienced by the individual due to this price change can be found by constructing $\pi_2\pi_2'$ parallel to $\pi_1\pi_1'$ and tangent to W_o. The consumer is thus as well off with income I_2 and the possibility of purchasing clean air along the budget constraint $\pi_2\pi_2'$ as he was in his original position (point A). The compensating variation measure of the welfare gain due to the price change is thus $I_1 - I_2$. The compensated demand curve, relevant for this price change is shown in Figure 4. The compensating variation is therefore given by area edc. Consider now a further decline in the price of clean air below π_1. Since the consumer has already purchased enough clean air to eliminate all pollution, he cannot purchase more. Further price reduction (to, say, zero) will therefore represent pure income gains for the consumer and are

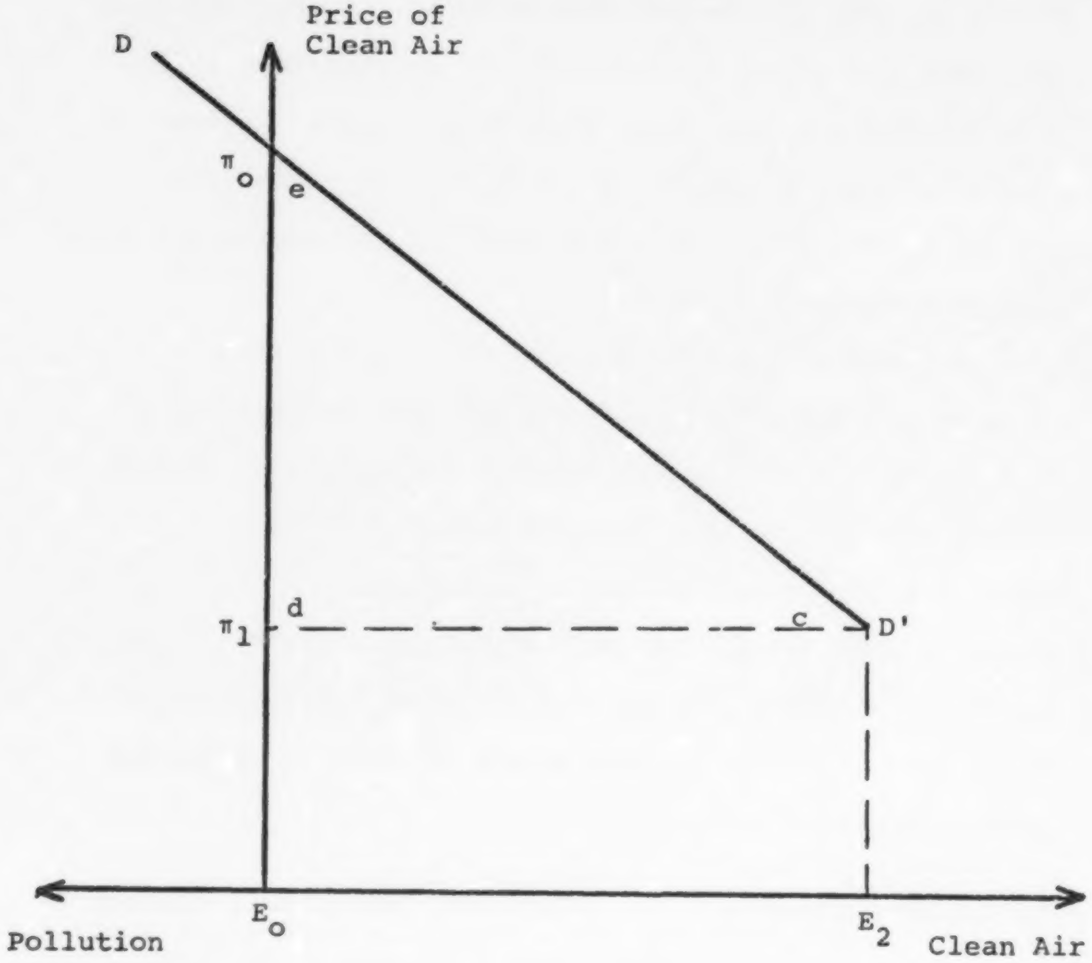

Figure 2.4 COMPENSATED DEMAND CURVES ON THE BENEFITS OF AIR POLLUTION CONTROL

represented simply by the income change $I_o - I_1$ in Figure 3. An attempt to measure the costs of pollution based on the area under the compensated demand curve would thus over estimate the costs of air pollution by amount $I_c - I_2$ in Figure 3. The reason for this apparent discrepancy is that when the price falls below π_1, the consumer is in a no-trade situation characterized by already pollution-free air, and the prices, in terms of which the goods are being evaluated, no longer reflect the consumer's relative marginal valuations.*

The second measure corresponds to the equivalent variation measure discussed earlier, and is relevant if we want to know now much a receptor of pollution should be compensated if the pollution is not eliminated. In this case we are interested in determining how much additional income would make the individual indifferent between living with zero pollution and income I_o, and living with a pollution level of P_o and income level of I_o plus the income compensation.

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*Hicks [27] suggested two additional measures of welfare change, the compensating surplus and the equivalent surplus, which constrained the individual to consume the same amount of the commodity whose price had changed before and after any compensation. In terms of Figure 3, $I_o - I_c$ would be the compensating surplus and $I_e - I_o$ the equivalent surplus. The welfare measure defined above is thus the same as Hicks' compensating surplus. The compensating and equivalent surplus measures have not been commonly used since in most applications there is no reason why the

The required income compensation is obviously $I_e - I_o$. As was the case with the compensating variation, a measure of this change based on the area under the compensated demand curve, holding the individual's welfare constant at level W_1, need not equal $I_e - I_o$. A more important point is the fact that $I_e - I_o$ need not equal $I_o - I_c$. In fact, while the size of compensating variation measure is bounded by the size of the individual's income, there is no such bound on the equivalent measure.* It should also be remarked, that if income effects are absent (so that the indifference curves in Figure 3 are equidistant at all pollution levels), the compensating variation measure will be equal to the equivalent variation measure. All of these measures are therefore given by relevant area under the compensated demand curve since ordinary and compensated demand curves will coincide in this case. Assuming the absence of income effects is, however, equivalent to assuming that the income elasticity of demand

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consumption of the affected commodity should be constrained at any particular level. In the present application, the kink in the budget constraint insures that the consumer will behave as if his consumption were constrained.

*The assertion that the compensating variation is bounded by the consumer's income assumes that the consumer's willingness to pay is constrained by his ability to pay, and that the negative consumption of goods is impossible.

for the external effect is equal to zero. This probably is not the case for many external effects. For example, most people would consider the emlimination of external effects such as noise and pollution to be non-inferior goods (see, for example, Paul [48] and Anderson and Crocker [1]). The definition of, and magnitude of, an external cost is thus not generally well defined or readily measurable. The appropriate measure will depend on the context in which it is to be used.

Extension to Many Individuals and Commodities

Up until now, we have discussed the measurement of external effects in a very special setting, consisting of one individual, an external effect, and a general composite commodity. We consider next the implications of aggregating the measures discussed above across more than one individual, along with the implications of considering the same problem in a general equilibrium setting with more than two commodities and distortions, taking into account the interaction between markets and individuals and the existence of market imperfections.

The theoretical aggregation problem can be stated as follows: Given some social welfare function, $SW(W^1, \ldots, W^n)$, which depends only on the welfare (or utility levels), $W^1, \ldots, W^n$, of the individuals in the society, is there some way of aggregating net benefit or cost measures over these individuals such that a change in the state of the economy resulting in a measured aggregate cost will always yield a lower value of the social welfare function? For example, assume that a change occurs which benefits some individuals and imposes costs on others. The question is then whether an aggregate based on measured (in terms of money) individual net benefits or costs exists which necessarily implies that social welfare has increased if the aggregate is positive and decreased if the aggregate is negative. The answer to this last question may be no if the change results in a change in the distribution of income, or if the initial state was not efficient. The importance of this question will be illustrated below. The problems associated with aggregating welfare measures are discussed in greater detail in Mohring [42] and Milleron [38]. Problems associated with redistribution effects are discussed by Weisbrod [57].

It can be shown that this is possible only for special cases. For example, national income, evaluated at current prices, does not satisfy the above requirement. Samuelson [52] showed that there does not exist any social welfare function, depending only on individuals' welfare, which always increases when national income increases (see Graaf [19, Ch.11] for a good survey of the literature on the interpretation of aggregate income measures). Similar problems arise when one attempts to aggregate individual consumers' surplus measures under general conditions. Some exceptions do, however, exist. In particular, Milleron [38] has shown that if individual utility functions are homogeneous, and if the social welfare function is a positive weighted sum of individual utilities, then it is in fact meaningful to speak of a social welfare function. He shows in particular that, under the specified conditions, a positive change in consumers' surplus is equivalent to an increase in the social welfare function.

These special conditions do not, however, hold in general (homogeneous utility functions imply unitary income elasticities of demand for all goods). The general approach in applied welfare economics has been to ignore these distributional and aggregation problems. In actual application, welfare measures have often been based on consumers' surplus computed from areas under aggregate (or market) demand curves instead of individual demand curves.* This implies that aggregate measured welfare changes are computed as the arithmetic sum of individual welfare changes. This will generally imply a welfare function in which the weights assigned to individuals depend on money incomes and prices since these determine the height of individuals' demand curves. Thus, cases may arise (see next paragraph) where a change results in a net measured gain if computed in terms of initial prices and a loss if measured in terms of post-change prices. There does not appear to be any ready way of avoiding such potential ambiguities, since we do not know which form of the social welfare function to employ.

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*A number of applications which base welfare measures on areas under aggregate demand curves are surveyed in Prest and Turvey [49]. Also see Burt and Brewer [10] and Harberger [22] for examples.

The relevance of aggregation problems can be illustrated by the following possibility. Consider a city which disposes of its solid wastes in landfills. It computes the external costs of operating these land fills under the currently prevailing distribution of income and set of prices and finds that these costs would exceed the cost of operating an incinerator under the same conditions. It may find, however, if it closes the land fills and installs the incinerator, that under the new conditions the external costs of the incinerator exceed the external costs of the landfills. This would be possible if, for example, the individuals who were affected by the land fill assign a lower cost to the externalities after the incinerator is built (due to changes in the distribution of income and prices) than they assigned to the same externalities before the incinerator was built.

Further complications arise when the existence of many commodities, external effects, and the possibility of interactions between different markets is explicitly recognized. We will discuss two major complications here, both of which should be treated in the context of a general equilibrium model.

A major criticism of the measures we have discussed above is that they are developed in a partial equilibrium framework, which does not adequately allow for the type of substitution possibilities and interactions which occur in an economy. For example, a waste disposal facility may pollute the water used by a manufacturing firm, increasing the cost of clean water to the firm. This in turn, may lead the firm to use less water-intensive production techniques, leading people to buy less water-intensive goods. At the same time, one would expect the prices of other factors and goods to change in response to the waste disposal facility. Only by comparing the value of the output (or output plus total consumers' surplus) of the economy before the change with the output after the change can a correct measure of the costs imposed by the pollution be obtained.

This is especially important if the effect is expected to have a significant impact on the pattern of economic activity within the relevant region or country. Thus, an analysis of the external effects produced by the Interstate Highway System should consider the possibility of country-wide changes. An analysis of a dump should consider the adjustment of economic activity within the local community.

That a general equilibrium approach can significantly affect measurements of welfare effects has been demonstrated in a number of contexts. Early efforts in the field, developed by Tinbergen [56] and Bos and Koyck [7], were schemes to estimate the benefits associated with new roads. They showed that the direct savings in transport costs attributable to a new road network could significantly understate the total benefits of the roads since the improved road system also allowed more efficient patterns of production. Similar results were obtained by Harberger [20] in his analysis of the welfare costs of the distortions produced by the corporate income tax. A more general framework for computing equilibria in models with and without distortions has recently been developed by Shoven and Whalley [54]. The theoretical work of Debreu [14] in developing measures of welfare costs in a general equilibrium model should also be cited in this context. General equilibrium analysis has also been used to analyze the geographic relocation of economic activities due to external effects. This is discussed in greater detail in Section D, where the relation between external effects and land rents is discussed.

The second major complication one encounters when one considers a more general framework is the possible existence of other external effects, distortions or imperfections in the economy. The implications of this possibility have been discussed in the welfare economics literature by Lancaster and Lipsey [31] under the heading of general theory of the second best (for further references and a correction see Santoni and Church [53]).

Complications arise since when more than one distortion or externality exists in an economy, the removal of a single distortion may actually reduce economic welfare. For example, taken by itself the excise tax on gasoline is a distortion, which reduces individuals' welfare more than is necessary for the amount of revenue it produces. Thus, by eliminating the gasoline tax and substituting an income tax of equal yield one would improve gasoline buyers' welfare (if the income compensated wage elasticity of supply of labor is zero). However, an increase in gasoline consumption and hence pollution may also result from this change. The net result of eliminating the gas tax may thus be a reduction in overall social welfare. The effects need not, however, necessarily be offsetting. For example, an increase in air pollution may increase the demand for air conditioners. If there is a further distortion in the economy in the form of an excise tax on air conditioners, the additional excess burden on purchasers of air conditioners should also be considered as a cost.

This again suggests that externalities should be valued in a general equilibrium framework. It should, however, be recognized that the theoretical and practical problems associated with a complete general equilibrium analysis may make the cost of such an approach prohibitive in many applications. An alternative strongly advocated by Harberger [21, 22, 23] is to identify all the markets in which a given action is likely to have a significant effect, compute the welfare gain or loss which results from the action in each of these markets allowing for relevant interactions, and then sum across all the affected markets to obtain a measure of the total welfare cost of the action.

In particular Harberger [23] suggests the following measure:

$$\Delta W = \int_{z=0}^{z^*} \sum_i D_i(x_i) \frac{\partial x_i}{\partial z} \, dz$$

where D_i represents net external benefits or costs in activity i, x_i represents the level of activity i and z is the policy variable. The summation is over all activities affected by the policy variable. This measure would improve on the standard Marshallian measure and deal with some of the general equilibrium problems discussed above. Harberger also suggests the measure can be readily applied in practice since the number of activities which, both are affected by any one policy and generate significant external costs or benefits, are likely to be small in most cases.

It may, however, be more difficult than Harberger suggests to correctly implement such a measure. It may, for example, be difficult to ascertain which activities will be affected by a policy without first performing a general equilibrium analysis of the policy being considered. If such a general equilibrium analysis is in fact performed, measures of external costs can be obtained more directly (see, for example, Shoven and Whalley [54]). In other words, it may be impossible to correctly assess the magnitude of the terms $\partial x_i/\partial z$ without a prior general equilibrium analysis of the problem. The Harberger measure may thus be fairly arbitrary if the affected activities are selected without a rigorous general equilibrium analysis or fairly costly if affected industries are selected correctly. Other, partial equilibrium measures which totally ignore general equilibrium problems are, of course, even more arbitrary.

Summary

We can summarize the results of this section as follows. If one abstracts from general equilibrium and aggregation problems external cost measurement based on either a compensating variation or equivalent variation concept is defensible in most cases. These measures can be computed directly from information about the individual's welfare function, or from areas under the appropriate compensated demand curves. The standard Marshallian measure, which is the one which has generally been used in attempts to measure non-market benefits or costs, will coincide with the above measures only if income effects equal zero.

The information requirements of both the equivalent variation measure and the compensating variation measure are, however, rather prohibitive. Estimates can be readily obtained if competitive price and quantity data are available and income effects are zero. If income effects are significant, these must also be estimated if compensated demand curves are to be obtained. Unfortunately, competitive price data are frequently unobtainable in the type of situation where measures of welfare changes are required. In some cases where competitive price data are unavailable due to distortions such as market imperfections and taxes, shadow prices which approximate competitive values can be computed (see, for example, Margolis [35] and McKean [37]). However, in cases where externalitites are important, markets may not exist in any form and the direct determination of competitive valuations or willingness to pay becomes very difficult for reasons which are discussed in detail in Section C.

Even in cases where measurement is feasible, care must also be taken to account for changes in other sectors or activities if distortions exist in these sectors.

C. INFORMATION PROBLEMS IN THE VALUATION OF EXTERNAL EFFECTS

It was shown in Section B that the valuation of an external effect requires fairly detailed information about the preferences of the receptor of the external effect. In this section we discuss some of the problems which arise when direct approaches are used to obtain such information. The discussion will relate, in particular, to cases where attempts are made to obtain the information directly by asking individuals how much they would be willing to pay to eliminate the externality (the compensating variation measure) or how much compensation would make them as well off with the externality as they were without it (the equivalent variation measure). (See, for example, Ridker [51, ch.5]). The discussion also applies to the somewhat less direct measurement approaches based on areas under compensated demand curves, since information about individuals' valuation of the externality is also required for estimates of these demand curves.

In this section we adopt Arrow's [2, pp.13-16] interpretation of an externality and assume that externalities are commodities which are exchanged among individuals, firms or agencies in the economy, but not traded in markets. In terms of the notation of Section A, if

$$\frac{\Delta w^i}{\Delta x_k^j} \neq 0$$

we can define a new set of commodities x_k^{ji} which satisfy the constraint

$$x_k^{ji} = x_k^j.$$

The variable x_k^{ji} thus represents the effect on individual i of commodity k when it is under the control of individual j. We also define the numbers N_k^j which represents the number of individuals, in addition to individual j, who are influenced (i.e., $\Delta W^i/\Delta x_k^j \neq 0$) by j's consumption of commodity k.

Most externalities differ, however, in important ways from ordinary private goods. In the case of an externality, one or more of the parties to the exchange is usually an involuntary partner. For example, in the case where the commodity x_k^{ji} is a good, it is usually difficult for the producer, j, of the good to exclude others from the benefits of the good. In the case where the commodity is a "bad", any reduction in the person's consumption often reduces other's as well; they cannot readily be excluded from benefits of a reduction in the bad. This problem of excluding individuals from the benefits of increases in external goods, or decreases in external bads is one reason why markets, which would provide evaluations of these commodities, fail to exist.

The possibility of exclusion is crucial for the direct measurement of externality since, whenever exclusion possibilities do not exist, individuals will not have an incentive to reveal correct information about their valuation of the commodity being considered. We should note, however, that the possibility of exclusion is not an absolute characteristic which a commodity has or lacks. In the case of some commodities the process of consumption or use automatically excludes all others from consumption. For example, the consumption of an ice cream cone (commodity k) by individual j excludes all others from its benefits (i.e., $N_k^j = 0$). In this case, the good is said to be rival in consumption and exclusion is not a significant problem (see Musgrave [46]). In other cases, however, exclusion problems do not prevent market allocation only because some agent or agency has incurred costs in the process of excluding people from their consumption. For example, amusement parks incur exclusion costs in the form of fences, security guards and other security devices. Exclusion is also supported by society through the expenditure of resources on police and institutions such as courts. In certain cases where exclusion would be impossible or too costly for the individual, society creates special institutions, such as patent rights in new inventions, in order to reduce exclusion costs. In general, a commodity lacks exclusion problems whenever it is rival in use or exclusion costs are low relative to the benefits the owner of the good could receive by excluding others from the consumption or use of the good.

On the other hand, in the case of commodities for which exclusion seems to be a problem, exclusion is often possible if the relevant agent is willing to incur sufficient costs. For example, a family living next to an open dump can reduce the visual offense by building a fence, reduce air pollution and odors by installing air conditioning and filtering devices, and reduce sound pollution by sound insulation. The exclusion problem thus arises when exclusion costs become large relative to the value of the commodity being traded. This would seem to imply that the exclusion problem is merely a matter of degree, and that if the exclusion problem is the only difficulty, then measurements and valuations of external effects can be obtained by incurring the necessary exclusion costs on an experimental basis. This may in fact be possible in certain cases and is discussed briefly at the end of this section.

However, even if an agency is willing to incur the required exclusion costs, the valuation process is often complicated by further public goods aspects of many externalities when many agents are involved (i.e., if N_k^j is large) and by bargaining problems when only a few agents are involved (i.e., if N_k^j is small). These problems can be illustrated by considering, for example, the problem of estimating the external costs that air pollution from a dump imposes on a community. We consider this problem in three special cases, the last two of which illustrate complications cited above.

Case I. Assume:

A.1) There are many individuals in the community who are affected by the air pollution.

A.2) Individual air pollution control is possible. By this we mean that it is possible, for finite cost, to eliminate the effects of air pollution for single individuals in the community without eliminating them for all individuals in the community at the same time.

We will also assume that the cost of providing individual pollution control is above most individuals' willingness to pay for pollution control. If it were less, there would presumably be a well-developed private market for such devices and a serious valuation problem would not exist. Under the assumed conditions the government, or the agency attempting to estimate the external costs, can, however, create an experimental market which would provide the information required to value the external costs.

The government could conduct the following experiment. It would offer to make local pollution control available at a price where just those individuals with the highest willingness to pay for pollution control would purchase the service. Once it has been determined which individuals are willing to pay this price, and what the economic characteristics of these individuals are, it would repeat the experiment at a somewhat lower price. By running a succession of such experiments in otherwise identical communities, the government can obtain all the information it needs to estimate the demand function for pollution control, which can in turn be used to estimate the external cost of the pollution. A number of communities (or a number of groups randomly chosen within the same community) would be required since, if successively lower prices were announced in a single community (or group), a serious expectations problem could arise. People with a high willingness to pay would have an incentive to conceal their true marginal evaluation in order to hold out for lower prices.

We can summarize Case I as follows. If assumptions 1 and 2 hold, there exists a purely private good called local pollution control. There is not a functioning market for this good because the price at which private firms would be willing to supply the good exceeds the price individuals are willing to pay.* There is therefore no market information available. Such information can, however, be obtained if the government makes the good available at a price which is less than the private supply price, either by producing and supplying the good directly, or by offering potential private suppliers a subsidy.

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*Normally, the fact that the supply price of a private good exceeds the demand price (what individuals are willing to pay) can be interpreted as an indication that the good should not be produced. We are interested in providing the good under these conditions in this case only as a means of obtaining information about peoples' willingness to pay for cheaper, but also less information producing, control strategies.

Case II. We replace assumption A.1 by:

A.3) There is only one agent who is damaged by the pollution (i.e., $N_k^j = 1$).

We begin by noting that assumption A.2 is now no longer necessary. When only one agent is involved it does not matter in the valuation process whether the pollution control is at the source of the pollution or at the site of the receptor since exclusion of other agents from the potential benefits of pollution control is no longer an issue. As Arrow [2] has emphasized, the problem of valuation in this case is related to the general indeterminacy of bargaining processes rather than exclusion problems.

In this case we are essentially dealing with a bilateral monopoly situation, in that there is one agency, the government, which is willing to provide pollution control and one potential purchaser of pollution control. Consider now an experiment similar to the one outlined under Case I. In particular, assume that the government offers to make pollution control available at less than cost in order to obtain information about the receptors' willingness to pay for pollution control.

The government wants to know the maximum amount the receptor would be willing to pay. It must therefore try to extract the maximum possible payment from the receptor. The receptor on the other hand wants to minimize his payments for pollution control. The outcome of the bargaining process will thus in general be indeterminate and bias the valuation downward, since the receptor will have an incentive to understate the damages he suffers from the pollution. In no case would a receptor offer to pay more for pollution control than his valuation of the damages imposed by the pollution.

An alternative would be to make pollution control available without requiring payment, but asking the receptors' willingness to pay for pollution control. In this case the receptor would have a strong incentive to overstate the damages suffered, in order to maximize pollution control.

Thus, whenever small numbers of agents are involved, it will in general be difficult to get information about external costs from market observations, surveys or experiments.

Situations arise, however, in which many individuals are involved, but local pollution control is not a relevant possibility. We therefore consider next:

Case III. We reinstate assumption A.1 and replace A.2 by A.4:

A.1) There are many individuals who are affected by the air pollution (i.e., N_k^j is a large number).

A.4) Pollution control is possible only at the source of the pollution.

In this case, pollution control becomes a public good for the community affected by the pollution and market experiments of the type discussed under Cases I and II are no longer possible. Assumption A.1 means that if the amount of pollution control is based on individual valuations, the information any one individual provides will have, at most, a very small impact on the level of pollution control which is provided. Assumption A.4 assures the individual that he will benefit from the air pollution control which is eventually provided, independently of information or misinformation which he may have provided. An individual will therefore have an incentive to frustrate the valuation of the pollution damage he incurs, since one of the following two situations will generally apply.

Consider first the case where the cost to the individual of pollution control is not related to the valuation the government places on the damages the individual incurs.

The individual could benefit in this case by overstating the damages he suffers, since his overstatement may encourage the government to provide additional pollution control at no cost to the individual. (This assumes, of course, that the marginal benefits of additional pollution control are always positive.)

The government may therefore decide to relate charges for pollution control to the benefits received from pollution control. In this case, the government will, however, run into the "free rider" problem,* since understatement by any one individual of his benefits would have only a small effect on the level of pollution control provided, but would presumably result in a significant reduction in marginal charges insofar as they are set equal to marginal stated benefits. In other words, the reduction in the marginal benefits the individual receives would be less than the reduction in his marginal charges. We would thus expect any direct measurement techniques to encounter serious measurement difficulties if actual conditions are approximated by the assumption of Case III.

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*See Buchanan [8] for a good discussion of public goods issues. The "free rider" problem is disscussed in Chapter 5. For a more rigorous discussion of public goods issues see Milleron [39].

We should also note, however, that considerably more sophisticated non-market experiments than those discussed above are possible. For example, one could announce that pollution control will be provided only if a certain amount in money payments is subscribed. In this case, if the individual does not know the target amount, or how much money other individuals have subscribed, the individual will realize that there is a possibility that a small understatement can result in no pollution control at all. Bohm [6] reports on a number of such experiments which attempt to determine the willingness to pay for broadcasting that obtain some apparently encouraging results. Theoretical issues in the design of such experiments have also been studied by Kamien and Schwartz [29, 30]. In general, however, very little is known about the properties of such experiments and further research, involving both the running of actual experiments, and the analysis of their general theoretical properties is necessary before any reliability can be attached to these estimates.

This section can be summarized as follows. Only under special conditions is it possible to obtain direct estimates of an individual's willingness to pay for an externality (or to pay for its removal). These conditions are that the externality have the characteristics of a private good, as in Case I, so that exclusion and bargaining problems are minimized. Unfortunately, situations similar to Cases II or III are much more likely to occur in the presence of external effects. For example, a dump may result in air pollution, an externality which usually results in direct measurement problems of the type discussed under Case III, and also in the pollution of ground water. This will give rise to a measurement problem of the type considered under Case II if water is distributed centrally through a municipal or privately owned water company. Direct measurement approaches of the type considered in Section B therefore do not appear to be promising without considerable basic research on experimental techniques. We therefore consider next a somewhat less direct approach to the valuation of external effects based on land rents.

D. MEASUREMENT OF EXTERNAL EFFECTS BASED ON LAND RENTS

Introduction

When the information required for the direct evaluation of the compensating variation measure (or related consumers' surplus measures) cannot be readily obtained, measures of external effects can still be obtained if the source of the external effect is specific to particular sites or locations, and the external effect is not uniformly distributed over the region. Under these conditions an individual or productive activity can avoid the external cost by relocating. The market for alternative locations will thus also be an indirect market for units of the external effect, and it should be possible to infer information about willingness to pay for the elimination of pollution from agents' transactions in this market.

Ideally, information on differences in land rents attributable to an external effect should measure the current cost or benefit of the effect. In cases where information on land rents is not available, land values, which are capitalized land rents, serve a similar purpose. However, in this case the linkage is less direct since the land values will reflect expected future (discounted) rents as well as current rents. The implications of this observation are discussed in greater detail at the end of this section.

The use of changes in land rents as a measure may also be advantageous when one wants to estimate the social costs of an activity producing a number of external effects since a single measurement may capture all of the external costs produced by the activity. For example, a dump that produces externalities in the form of noise, air pollution and a health problem due to vectors, will effect land values due to all of these externalities. The change in land rents attributable to the dump will thus be a measure of all three external costs.

The Theoretical Framework

In a partial equilibrium setting the use of differences in land rents as a measure of external effects can be justified by reference to the classical theory of rents.* This theory assumes that no pure profits remain in a competitive equilibrium. Thus, if a piece of land is more productive in farming than adjacent land, potential farmers will bid up the rent of the land until it is no more profitable to farm it than the surrounding land. Similarly, if a piece of property suffers pollution damage, its rent will fall relative to similar land until it is as profitable to utilize as the surrounding land. Thus the full cost of the external effect should be reflected in the land rent. This relationship between external effects and land values was first investigated in a partial equilibrium setting. Mohring [43, 44], for example, performed some detailed studies of the relationship between land values and transportation improvements.

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*See Mishan [41] for a discussion of the relation between rents and other welfare measures. He concludes, in a partial equilibrium setting, that economic rent and consumer's surplus are formally equivalent (measure the same thing), the first being computed with reference to supply prices, the latter with reference to demand prices.

The approach described above is, however, in general deficient since it does not allow for changes in the pattern of land use. The problem becomes considerably more complicated when such changes are considered and a general equilibrium approach is required. The problem was first considered in this setting by Strotz [55] who considered a simple general equilibrium model with two types of land, which are identical except that one was affected by pollution. He found that a first order approximation to the compensating variation measure of pollution costs is equal to the sum of the absolute value of the changes in all land rents in the system.

This work was extended by Lind [32,33] who considered the problem as an optimal assignment problem in a general equilibrium setting.* He assumes that there are m parcels of land and n activities in the economy. An activity is either a production activity, such as farming, factories etc., or a consumption activity, such as residential housing. Let a_{ij} be the maximum amount activity i is willing to pay for parcel j. The value of a_{ij} will in general depend jointly on the activity and the parcel.

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* For a discussion of the assignment problem see Beckmann and Koopmans [5] or Gale [18].

In terms of the classical theory of rents, it is the maximum rent the owner of parcel j can extract from a renter engaged in activity i.

The optimal assignment problem is now one of assigning the n activities to the m parcels in such a manner that the sum of the a_{ij} is maximized. This can be transformed into a linear programming problem by defining a set of choice variables s_{ij} $i=1,\ldots, n; j=1,\ldots, m$, such that $s_{ij} = 1$ if activity i locates on parcel j and is zero otherwise. The problem can then be stated as follows:

$$\underset{\{s_{ij}\}}{\text{MAX}} \quad \sum_{i}^{n} \sum_{j}^{m} a_{ij} \, s_{ij}$$

SUBJECT TO:

$$\left.\begin{array}{l} \sum_{i} s_{ij} \leqq 1 \\[2em] \sum_{j} s_{ij} \leqq 1 \end{array}\right\} \qquad \begin{array}{l} i = 1,\ldots, n, \\[2em] j = 1,\ldots, m. \end{array}$$

The constraints ensure that at most, one activity will occupy each parcel of land and that any given activity is assigned to only one parcel.

Let p_j be the rent on a parcel j arising from a competitive equilibrium. It can then be shown that there exists a set of equilibrium rents such that if parcel j is used for activity i in the optimal assignment:

$$a_{ij} \geq p_j \tag{2.1}$$

and

$$a_{ij} - p_j \geq a_{ij} - p_k \qquad k = 1, \ldots, n. \tag{2.2}$$

Note that these conditions ensure that activity i is not loosing money when it locates on parcel j (2.1) and that there is no better location for it (2.2). These rents will in general not be unique, but Lind proves that any equilibrium rent vector, p, will lie in an interval $\overline{p} \leq \overline{p} \leq \overline{\overline{p}}$, where both $\overline{p}$ and $\overline{\overline{p}}$ satisfy (2.1) and (2.2). The actual rent vector obtained in a given situation will depend on factors such as actual market adjustment mechanisms, bargaining strengths, etc.

Consider now the relationship between land rents and net benefits (or costs) from changes in an external effect. Define $c_i = s^*_{ij} (a_{ij} - p_j)$ for each i (where s^*_{ij} represents the values of the variables s_{ij} chosen in the optimal assignment). For a consumer, c_i represents the consumers surplus consumer i receives from his (optimal) selection of parcel j. For firms, c_i is the profit of firm i when it selects parcel j in the optimal assignment. Thus, it is obvious that the net social benefits from the use of land are

$$\sum_i \sum_j s^*_{ij} a_{ij} = \sum_i c_i + \sum_j p_j .$$

Consider now, for example, the elimination of an external cost in the system; this will enhance, by definition, the value of at least a subset, Q, of the parcels of land in the system. Let a'_{ij} be the values of land parcels associated with this new state of affairs. By definition

$$a'_{ij} > a_{ij} \text{ for some } i = 1,\ldots, n \quad j \in Q ,$$

and

$$a'_{ij} = a_{ij} \text{ for all } i = 1,\ldots, n \quad j \in N-Q .$$

Now, for simplicity, renumber activities such that activity j is assigned to parcel j in the old optimal assignment. Let $\pi(j)$ be the new optimal assignment of activity j. Thus, obviously, total net benefits from elimination of the external effects are give by

$$\sum_j (a'_{j\pi(j)} - a_{jj}) = \sum_j (p'_j - p_j) + \sum_j (c'_{j\pi(j)} - c_{jj}). \qquad (2.3)$$

Thus, land rent changes equal the change in total social net benefits only if the final term of (2.3) is zero. This means that all firms must earn zero profit, or that the sum of the profits specific to parcels are unchanged in the new assignment, and likewise for the consumers' surplus of households. This is an extremely strong requirement, especially with respect to households; it requires that the consumers' surplus of the households be, in sum, the same in the old and new assignment. There do not appear to be any economic reasons why this sum should in general increase, decrease, or remain constant.

The problem as stated also requires evaluation of the changes in the rents of a large number of parcels in the system. Lind makes a major contribution here by showing that changes in the rents and surpluses of activities which do not locate on sites directly affected by the external effect will sum to zero.* We thus need be concerned only with changes in the productivity or surpluses of those activities which are directly affected. This reduces the computational problem significantly for those projects or activities, such as a solid waste disposal site, which affect only a limited number of locations.

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* The proof of this proposition uses properties of permutations and the equilibrium conditions discussed above. For a more detailed discussion see Lind [33, pp. 194-201].

Limitations of Measures Based on Land Rents

The theory developed above also points to some deficiencies most land rent studies are likely to have. First, given the assumptions of the assignment problem model, the correct (compensating variation) measure of external costs or benefits is given by (2.3). As we noted, this measure will equal the change in land rents only if the sum of the surpluses earned on all parcels remains unchanged. True costs may thus be either greater or less than the measured changes in land rents, depending on whether the sum of the surpluses increased or decreased after the change.

Further complications arise when some of the assumptions of the model are relaxed. In particular, the model takes the willingness of each activity to pay for a given parcel of land as given. It determines an optimal assignment and equilibrium rent vector assuming all other prices for factors and goods remain constant. If this is the case, any benefit or cost from an externality affecting a parcel of land will accrue to that parcel in the form of a change in rents to its owner, or a change in the surplus or profit of the activity occupying the parcel. If, however, the product or factor prices of the activity occupying the parcel also change because of the external effect, it is no longer true that all the benefits or costs will be reflected by (2.3). In this case, the compensating variation measure would require that the a'_{ij} be evaluated on the basis of prices existing before the external effect occurred.

The relevance of the Lind model is thus limited to the effects of activities which do not disturb the equilibrium prices in markets other than the market for land. It is thus probably relevant for the evaluation of external costs associated with particular solid waste disposal facilities. It may not, however, be appropriate for estimating the benefits or costs of any national policy, altering the pattern of waste disposal. For example, a national policy closing all dumps and landfills may significantly affect aggregate waste disposal costs and hence prices in other markets.

Lind notes, however, that in the case of the housing market, even relatively small and local projects may have significant price effects, since the price of housing services is determined in part by the local supply of land suitable for housing. In this case, a more general model relating rents to the external effect which also takes price determination in the housing market as well as land rents into account would be appropriate. However, such models turn out to be exceedingly complex, especially if analytical solutions are desired, as the recent work by

Beckman [4], Delson [15] and Montesano [45] shows.

Further complications may arise when one tries to estimate the relevant rents, p_j' and p_j, in (2.3) since in most cases available data relate to land values, rather than land rents, and land is typically improved.* We consider first the problems of converting changes in land values to changes in land rents. In general, the relation between the value, v, of a parcel of land (valued at time t = 0) and its rent is given by

$$v = \int_0^\infty p(t)e^{-rt}dt \qquad (2.4)$$

where r is the purchaser's discount rate.+ Equation (2.4) integrates to

$$v = \frac{p}{r} \ , \qquad (2.5)$$

if p(t) = p for all t (i.e., if the rent does not change over time).

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*In certain cases measures based on land values may be preferable. This possibility is discussed briefly at the end of this section.

+The determination of the consumers' discount rate can also present serious problems, since there appears to be no concensus on what this rate should be. Estimates range from 5% to over 30%. See Arrow and Kurz [3, pp. 117-119] for a brief discussion.

Now assume that a dump is opened next to the land parcel in question, causing the equilibrium rent of the parcel to fall to $p'(t) = p'$, and that the market expects the dump to continue in operation forever. Then clearly,

$$p' - p = r(v' - v)$$

where v' is the value of the parcel after the dump is opened. Thus, the changes in rents can be obtained from changes in land values if the appropriate discount rate is known and if the externality is expected to last forever.

If, however, the dump is expected to last only a finite period of time, additional information is required. Assume that the market expects the dump to close after a period of T years. Then

$$v' = \int_0^T p'e^{-rt}dt + \int_T^\infty pe^{-rt}dt$$

which becomes on integration:

$$v' = p' \frac{(1-e^{-rT})}{r} + \frac{pe^{-rT}}{r} \quad . \qquad (2.6)$$

Subtracting equation (2.5) from (2.6) and solving for $p' - p$, we obtain:

$$p' - p = (1-e^{-rT})^{-1} r(v' - v). \tag{2.7}$$

Thus knowledge of how long, T, the externality is expected to continue in effect is required. More complicated time paths of the rents are of course possible; this example merely illustrates the existence of a problem.

Another problem is that buildings or other improvements are generally situated on parcels of land where the measurement of externalities is considered important. The assignment model developed above indicates that it is only the value of the land itself which is affected by the externality. However, this is true only when all activities which find it profitable to relocate have done so. Where improvements are durable, such as in the case of houses and factories, the adjustment to a new equilibrium may require a relatively long period of time. If this is the case, the value of the improvements on a land parcel may be affected by an externality while the parcel itself is not affected. For example, a home site exposed to noise pollution may be equally valuable as a junkyard location. In this case, the value of the home will decline due to the noise, but the land will not decline in value. Thus, the external costs of the noise measured in terms of changes in equilibrium land rents will be zero. The value of the home, however, will decline as a result of the noise, the amount of the decline depending on both the amount of noise and the expected life of the house (the length of time until a new locational equilibrium is attained).

A problem thus exists in studies where the available price data are for both the land and any improvements. Assume in the example above that the noise is from a source which is expected to continue in operation for an additional 20 years, but that the house has an expected life of 10 years. Then, if the noise affects the productivity of the land, the change in value of the land would be converted into rents based on a 20 year horizon (by solving for p' and using T=20). On the other hand, if it is assumed that the noise affects the improvement on the land only in its current use, the appropriate horizon becomes 10 years, implying a higher current annual external cost from the noise.

Whether or not the problem of going from land values to rents is a significant one will, of course, depend on the context in which the measurements are to be used. If compensation for damages is being considered, the land value figure is probably the most important. If, on the other hand, one is trying to determine whether a given annual expenditure to alleviate the effects of the externality is justified, the land rent figures would be preferred. One possible alternative in the latter case would be to discount future expenditures on externality control by the public discount rate and compare the capitalized cost with the land values. This procedure would still require knowledge of the time path of the externality, however, plus knowlege of the appropriate public discount rate.

Measures of external costs based on changes in land rents may also result in underestimates of social costs since disequilibrium conditions may persist for long periods of time due to adjustment costs. Paul [48], for example, notes that in the case of residential housing moving costs may be substantial. Thus, a family which is adversely affected by the noise generated by a new dump may not relocate if moving costs exceed the costs imposed by the noise. The value of their house and land may not, however, be affected if there exist potential buyers who are unaffected by the noise. The noise costs incurred by this family would thus be omitted in a study of the social costs of the noise nuisance which is based on changes in land rents. In the case where the noise costs exceed moving costs, and an optimal assignment of families to residence sites occurs, the measure based on land rents would still understate total social costs by the amount of the moving costs.

A number of additional problems also arise when one attempts to obtain empirical estimates of the impact of an activity producing external effects on a set of heterogeneous sites. These problems, which relate to the correct specification of an econometric model which would explain differences in equilibrium land values, are discussed in detail in Chapter III.

E. SUMMARY AND CONCLUSIONS

We can summarize the principal conclusions of this chapter as follows. There are serious conceptual problems associated with even defining "the cost" of an external effect, since the appropriateness of any given definition depends on the specific application of it. Given an application, however, the external cost can be defined and measured directly given sufficient information about the preferences of the receptors of the external effect. Such information is however in general unobtainable, making alternative indirect measurement approaches, such as property value studies, look appealing. The principal advantage of these approaches is their less stringent data requirements. A further advantage is their ability to capture the effects of any number of externalities, produced by a given activity, in a single study.

There are, however, also a number of problems associated with property value studies. In many applications they may only be suggestive of costs, instead of being correct measures of social costs. Problems arise when the total surplus (profits and consumers' surplus) change due to an activity, when the activity will occur for only a limited time and when there are adjustment costs in moving from one optimal assignment to another. Further problems, which are discussed in Chapter III, arise when one attempts to obtain empirical estimates of changes in land values attributable to an externality producing acitivty.

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CHAPTER III

THE VALUATION OF EXTERNAL EFFECTS: EMPIRICAL STUDIES

A. INTRODUCTION

This chapter surveys and evaluates attempts which have been made to obtain empirical estimates of the money value of externalities produced by an activity, such as a dump or landfill. Studies related to two alternative valuation strategies are discussed. One approach to measurement and valuation employs a two stage procedure. In the first stage one would obtain estimates of all of the physical effects produced by an activity which are not valued, or incorrectly valued in competitive markets. In the second stage a net dollar value is assigned to each of these physical effects. The basic objects of analysis are thus the physical effects of an activity. Studies related to the evaluation of individual physical effects are surveyed in Section B. The alternative approach takes as the basic object of analysis the activity itself, and attempts to obtain estimates of the non-market benefits or costs of the activity taken as a whole.

This approach is implicitly used in most studies which relate differences in equilibrium land rents to externalities. These studies are surveyed in Section C. Both of these approaches to measurement and valuation are discussed in greater detail below.*

The first approach outlined above has been advocated by analysts who believe (taking a study of the benefits of air pollution abatement as an example): "Consumers are dreadfully ignorant of the benefits of abatement" [42, p. 214]. Lave [42] thus believes that attempts to ascertain directly an individual's willingness to pay (either explicitly by asking the individual in a way that will elicit an honest answer or implicitly by observing his behavior in a related market such as the land market) for the elimination of an external cost producing activity are likely to yield estimates of benefits which are biased downward.

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* It should be noted that other taxonomies of approaches to the measurement of external effects have been proposed. Ridker [65] suggests three major classifications: (1) calculate the physical effects and then calculate the value of these effects in terms of money. (2) Estimate the expenditures an individual incurs in adjusting to the effects of an activity. (3) Evaluate the change in consumer and producer surplus in the markets affected by an activity. This is similar to the taxonomy of approaches to the valuation of physical effects used in Section B.

The first approach attempts to avoid this problem of possible consumer ignorance by first determining the physical effects of an activity. For example, air pollution may affect health, soil clothes and materials, corrode materials, and have aesthetic effects (a detailed analysis of the physical effects of landfills is presented in Chapter IV). These effects can then be valued in terms of money using the type of measures which were discussed in Section B of Chapter II. If, for example, it is determined in the first stage that the elimination of pollution reduces the probability of contracting bronchitis by 10 per cent, the second stage must determine what affected individuals are willing to pay for such a reduction in the probability of contracting the disease.

The second approach ignores the possibility of ignorance on the part of individuals affected by an activity and assumes that individuals' money valuation of the activity accurately reflects its non-market costs and benefits. The only problem facing an analyst employing this approach is thus the determination of these money valuations. Since the direct determination of these money values through the questioning of affected individuals is likely to give biased results for the reasons discussed in Chapter II, Section C, the information required to value the activity is usually inferred from individuals' behavior in related markets, such as the market for land.

Which of the two measurement approaches outlined above will yield more meaningful estimates of the dollar value of external effects will depend both on the assumptions one makes about consumer ignorance and the quality of the information available for each approach. If consumers are unaware of the external physical effects of an activity, but an accurate evaluation of these effects can be obtained, the first approach should be preferred. If, however, individuals are aware of the physical effects of an activity, the quality of the estimates produced by each approach will depend on the quality of the data used in each case. For example, much better data may be available on willingness to pay to reduce the probability of contracting a disease than is available on willingness to pay to avoid air pollution.

It may, however, also be difficult to obtain accurate estimates of the physical effects of an activity, or to even identify all of the physical effects, and to value them precisely (See Lave [42] for a discussion of such problems in the case of air pollution). If this is the case, and adequate data are available on individuals' valuations of the activity as a whole, the second approach may be preferrable. The second approach may also be preferrable since it involves only the valuation of a single activity, whereas the first approach involves the estimation (of possibly a large number) of physical effects and their dollar valuation. In particular if a large number of effects are involved in the first approach one would expect it to be the more costly approach in terms of computation and data requirements. There are also more possibilities for error in the first approach since significant physical effects may be omitted, inaccurately estimated, or incorrectly valued.

It should also be noted that the distinction between an activity and the physical effects of the activity may be fairly arbitrary. For example, one of the physical effects of a burning dump may be the release of particulate matter into the air. Given this pollution one can, however, consider the new activity of pollution control, which may have as its physical effects a reduction in the incidence of disease and soiling of materials. The distinction between the two approaches to the evaluation of the external effects of an activity is thus not very sharp. Similar methods of determining willingness to pay (for the elimination of an activity or the elimination of a particular physical effect of an activity) are often applicable with both approaches. There may thus be as many problems involved in the valuation of a single physical effect (such as a decrease in the incidence of a disease) as are involved in the valuation of an activity as a whole (such as a program to decrease pollution levels).

A further problem may arise in the first approach if there are significant interactions between individual effects. For example, if air pollution affects an individual's enjoyment of outdoor living (due to respiratory problems) and also damages his flower garden, the sum of the damage to the flowers (evaluated without taking into account the effect of pollution on the individual's enjoyment of outdoor living) plus the damage to the individual in terms of his enjoyments (evaluated without taking into account the diminished beauty of his garden) may overstate total pollution damages. The problem of interactions need not arise with the first approach if care is taken in evaluating each physical effect at the equilibrium levels of the remaining effects. This may, however, be difficult in practice due to a lack of information or awareness about interaction effects. The problem will not, of course, arise in the second approach since it measures only the net effect of the activity overall.

Examples of both approaches are surveyed in the remainder of this chapter. The survey of approaches to the valuation of physical effects is highly selective since most cost-benefit studies can be interpreted as employing such approaches, and the cost-benefit literature is voluminous. The survey of the literature relating externalities to land rents or values is more comprehensive since this literature is shorter. It is also the approach employed to evaluate the external effects of landfills in this study.

B. THE EVALUATION OF EXTERNALITY PRODUCING ACTIVITIES THROUGH THE ESTIMATION AND EVALUATION OF PHYSICAL EFFECTS

Most of the attempts to obtain estimates of the dollar value of the external effects (and other non-marketable outputs) have occured in the context of cost-benefit analyses of economic activities such as water resources development, transportation, recreation, education and pollution control projects. The most common approach taken in these cost-benefit analyses has been to enumerate and estimate the magnitude of all of the physical effects, and then to evaluate these effects (i.e. the first approach discussed in the introduction).

Two measurement problems thus arise in these cost-benefit studies: the estimation of physical effects and the evaluation of these effects in terms of money. While the difficulties involved in obtaining measures of physical effects may be substantial in many cases, they are not discussed in detail in this chapter since they are primarily technical, rather than economic. The problems involved in determining the physical effects of landfills are discussed in detail in Chapter IV. In this section we emphasize the dollar valuation of physical effects.

The conceptual issues involved are discussed in detail in Section B of Chapter II. We survey here the approaches which have been used to obtain empirical estimates. Most of these studies attempt to estimate the Marshallian consumer's surplus for the physical effect which is consumed. Since these effects are not in general marketed, the major problem faced in these studies is acquisition of information on individual valuations of the physical effects which can be used to estimate the demand curves. In the remainder of this section we survey selected applications of various approaches which have been used to abtain such information.

Direct Market Information

In some cases the physical effect produced by an activity is also marketed. A good example of such an externality arises in the construction of many hydroelectric generation projects. If a new dam is constructed upstream from existing dams, the generating capacity of existing downstream facilities may be increased significantly through improved water storage and flow control. It was estimated for example that the construction of the Hungry Horse dam on the Columbia river system would provide 212,000 kilowatts of on-site generating capacity and increase the capacity of downstream sites (controlled by a number of different utilities and the U.S. government) by 628,000 kilowatts (See Krutilla and Eckstein [39, p. 62].

In this case accurate measures (in terms of kilowatts) of the externality are readily available. Since market prices for electricity are usually available the valuation problem is trivial if the project does not affect this market price. If the project does affect the market price, the proper evaluation would require the estimation of this price effect, and the computation of the consumer surplus generated by the incremental electricity supplied. In Figure 3.1 let x represent the total generating capacity in the market, D(x) represent the market demand for electricity, and $q'_x - q_x$ the increment in generating capacity due to the externality. The Marshallian measure of the value of the electricity is then given by area $q_x bcq'_x$ since this generating capacity is produced at zero marginal cost to the facilities where capacity has been increased.

Market data have also been used in a number of other studies. One of the major effects of many transportation projects is the time saved by affected individuals. The price at which this time is valued is often based on market wage information (See for example Foster and Beesely [19], Moses and Williamson [53], and Gronau [24]. Another example is the use of information about consumer expenditures on marketed recreation activities to value the output of recreation facilities whose output is not marketed (See Mack and Myers [44, pp. 78-88]).

In cases where such comparable private commodities exist and are marketed the approach discussed above should produce good estimates of the dollar value of

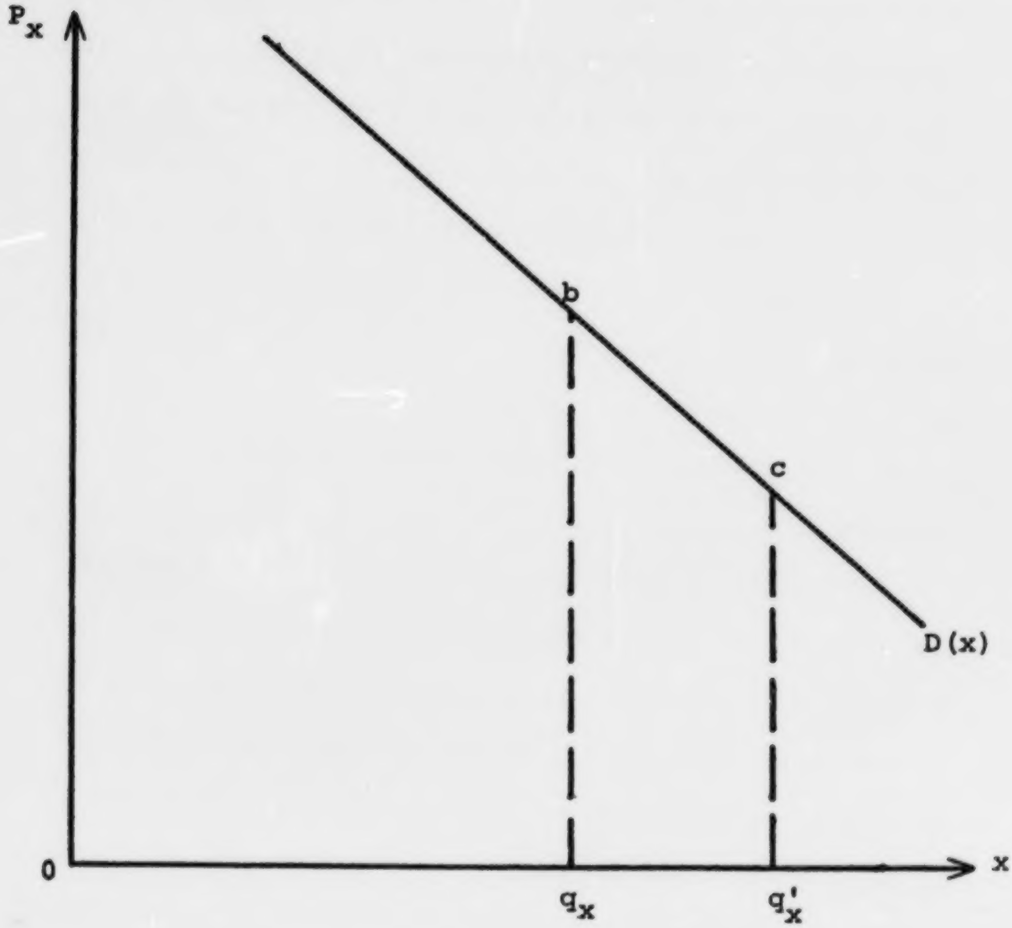

Figure 3.1 THE BENEFITS OF AN EXTERNALITY IN HYDROELECTRICITY GENERATION

the physical effects, subject to the theoretical qualifications about consumers' surplus measures discussed in Chapter II. In many cases, however, such close substitutes do not exist. Caution also should be exercised since valuations may be seriously distorted if the prices used are not competitive valuations (See the sub-section on the intermediate input approach for a further discussion of this point).

Direct Interviews of Recipients

In cases where market information is unavailable it is tempting to ask individuals what they would be willing to pay for a physical unit of the external cost or benefit, and to estimate demand functions from these data. This approach has been used extensively to value recreation benefits. Recent applications are studies of a Maine forest area by Knetsch and Davis [38]; crowding in wilderness areas by Fisher and Krutilla [18]and water fowl related recreation by Brown and Hammock [7] . The approach has also been used to obtain estimates of pollution damage and willingness to pay for air quality. See for example the study of a pollution episode in Ridker [65, Ch. 5] and the studies cited in Anderson and Crocker [3, p. 145]. Schelling [70] has suggested a similar approach to the valuation of programs having health effects. He suggests that an activity which changes the probability of illness, injury or death can be evaluated *ex ante* by asking the affected individuals their willingness to pay for changes in such probabilities. Schelling notes, however, that problems exist in the valuation of events having very small probabilities and very high associated gains or losses (See also Mishan [49, Chs. 22,23]).

The Intermediate Input Approach

It has been noted that many non-marketed goods such as public goods or externalities enter as inputs (positive or negative) into the production process of commodities which are sold in competitive markets (See Musgrave [54] or Margolis [46] for example). In this case it is often possible to estimate the dollar value of an externality of public good by estimating the value of its marginal product in further production.

For example, the dollar value of irrigation water* produced by water resources development projects is often calculated by estimating the increase in the income of farmers using the water, which is attributable to their increased use of irrigation water (See Bain [4] for example). The intermediate input approach has also been used to estimate the value of public education and public health programs. Education is valued by estimating the increase in the future earnings which can be attributed to education (See for example Becker [5] or Weisbrod [75]). Health and safety programs are evaluated by computing the increased productivity of affected individuals. This may take the form of increased output while working, increased output due to fewer sick days or increased output due to lengthened life spans (See Mushkin [55], Weisbrod [73, 74] or Rice [64]). For a general equilibrium analysis of transportation projects viewed as an intermediate input see Bos and Koyck [6].

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*The output of irrigation water from a project is not usually an external effect as defined in Chapter II. Evaluation difficulties arise, however, since irrigation water is often supplied at non-market prices and significant distortions exist in related markets. Krutilla and Eckstein [40, pp. 56,57], however, also

A shortcoming of the intermediate input approach

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cites a case where irrigation has improved aquifers, thereby increasing the output of irrigation water in other areas. This would be an externality of the type discussed in Chapter II.

is the fact that it must be regarded as only a partial evaluation in many cases. Education, for example, produces benefits other than increased earnings capability in the form of direct consumption benefits to the student and "citizenship" benefits to the community (See Weisbrod [75], Paul [60]). Health produces individual benefits in the form of reduced pain and suffering, increased comfort and lengthened life expectancies among unemployed and retired workers which are not reflected in increased earnings. The treatment of a communicable disease may also produce additional community benefits if the probability of further transmission is reduced (See Klarman [34]).

A further potential problem arises in the intermediate input approach (and in other approaches which use market data) if the final output is not sold on a competitive market. In this case a social shadow price which reflects individuals' willingness to pay for incremental units of the final output should be used to value the output, instead of the observed market price. For example, to the extent that farm output is subsidized, a downward adjustment should be made to valuations based on changes in the value of farm output (See Bain [4]). Shadow prices have also been used to allow for tax distortions, monopolistic conditions, unemployed resources and uncertainty. The problems that arise in estimating shadow prices are very similar to those that exist for externalities. For a discussion see McKean [47], Margolis [46], Mishan [49,Ch. 12] and Haveman and Krutilla [27].

Indirect Market Information

It is sometimes possible to obtain information about the value of an external effect which is not marketed from individual responses in markets for related goods. For example, the travel costs an individual incurs in order to reach a recreation facility can be interpreted as a part of the price an individual pays for the use of the facility. Since people generally live different distances from recreation facilities, and incur different costs to consume recreation benefits this information can be used to estimate a function relating the average use of a facility per person (visits per 1,000 population per year for example) to the price (i.e. costs incurred). This relationship and data on the distribution of people around a facility can then be used to construct a demand curve indicating how many individuals would use the facility if a price, in addition to travel costs were imposed for the use of the facility. The area under this demand curve is then a consumers' surplus measure of net benefits produced by the facility. This procedure is proposed and discussed, but not implemented empirically in Clawson and Knetsch [10, Chs. 5,11]. For a good formal discussion of the theoretical issues and an empirical application to water based recreation in Missouri see Burt and Brewer [8]. For another recent application see Mansfield [45].

In many cases where it is not possible to readily ascertain the demand for an activity or physical effect from the demand for related goods, as was the case in recreation, these markets may still provide useful information in the form of bounds on possible costs or benefits. For example, if households who live near a dump purchase more rat poison than other households in otherwise similar circumstances, these expenditures can be interpreted as a lower bound on the externality vectors from the dump impose on the community. Similarly, added expenditures on cough medicine may provide a partial measure of air pollution costs.

This approach has been applied extensively in the evaluation of pollution and health effects. Ridker [65 , Ch. 4] estimates some of the costs of air pollution by examining cleaning, maintenance, and painting expenditures in polluted and unpolluted areas. In a similar vein Lave [42] suggests that consumer expenditures (including power) on air filters and precipitators which reduce indoor pollution would provide a measure of air pollution costs. Costs currently incurred in the treatment of a disease will, of course, provide a lower bound on the benefits the community would receive from its eradication (See Klarman [34]).

The value of individual physical effects, and of activities taken as a whole, can also be estimated from individuals' market responses in the land market. These studies are discussed in detail in the next section.

C. EMPIRICAL STUDIES RELATING LAND VALUES TO EXTERNALITIES

This section has two major parts. In the first part we discuss problems and issues which arise in the specification of econometric land value studies. The second part surveys the important features of a number of major land value studies.

Problems and Issues in Specification

We consider first the empirical problems that arise when one attempts to measure externalities using land values or rents. Problems arise because the parcels of land, and their improvements, are heterogeneous commodities. Each parcel of land differs from all others with respect to its location by definition. It may also differ in terms of topography, soil conditions, the accessibility of utilities, zoning regulations, etc. Improvements may also differ in terms of a large number of characteristics, all of which affect the value of the land or its improvements. The determination of the effects of an externality on land values thus becomes a major problem. For example, is lot A, which is closer to a dump than lot B, less valuable because of the odors of the dump, because it has a poorer view, or because it is further from a local shopping center? The answer is, of course, possibly all three. In this case, the problem becomes one of determining how much of any difference in land values to attribute to each of the characteristics.

The usual approach to this problem has been to postulate that the value of a site i, v_i, is a function of the characteristics of the site, $z_{i1},\ldots,z_{ik}$, where z_{ij} is a measure of the j^{th} characteristic of the i^{th} site. It is assumed that this list includes measures of all relevant external effects, thus

$$v_i = f(z_{i1},\ldots,z_{ik},u_i). \tag{3.1}$$

The term u_i is an error term included to allow for the possibility that relevant characteristics have been excluded and random disturbances. This approach was first developed in the study of price indexes in order to permit comparisons of goods having different characteristics. A recent survey of this literature can be found in Griliches [23]. For more theoretical treatments of commodities having multiple characteristics see Lancaster [41], Quandt and Baumol [63] and Rosen [67]

The approach has been used in recent years to estimate the effect of a broad range of phenomena on land values. Applications include studies of the effect of racial discrimination in rental housing by King and Mieszkowski [32], the effect of airport noise on land values by Emerson [17], highways and land values by Mohring [50], air pollution and land values by Anderson and Crocker [1,2], solid waste disposal sites by Havlicek, Richardson, and Davies [28], and urban renewal by Rothenberg [68,69].

There are a number of methodological issues and questions which arise in these land value studies. A major problem is the fact that most of the literature looks at the value of land and improvements, with obvious problems. The effects of these improvements must be controlled for by including their characteristics in equation (3.1). Many issues arise, however, in the selection of such variables. It must be determined which variables, in addition to a variable representing the effect being studied, determine property values and should be included in a regression analysis. There have been several studies, in addition to those cited above, exploring this question. The studies by Kain and Quigley [30] and Grether and Mieszkowski [22] should be noted in particular. These studies attempted to identify and examine the significance of many different characteristics. Kain and Quigley, using a sample of residential homes, subjected a total of 39 variables representing the visual and physical quality of the homes and their neighborhoods to a factor analysis. They found that a five factor solution "accounts for 60% of the variance among the 39 original variables and seems to provide the most meaningful description of the quality dimensions of residential services" (Kain and Quigley [30 , p. 534]). The five factors were identified with: (1) the overall condition of the structure, landscaping and neighborhood (i.e., the overall exterior physical environment), (2) the interior quality of the structure, (3) the condition of neighboring properties, (4) the effect of commercial and industrial land use in the immediate vicinity and (5) the average structural quality of the neighborhood. The factor analysis does not provide any information about the economic importance of any of the factors in determining the price of a property. The factors do, however, give some indication of the independent dimensions of properties, all of which should be considered when one investigates the determinants of property values.

The paper by Grether and Mieszkowski employs an even larger set of independent variables. They explicitly consider three types of variables; structural, lot and neighborhood characteristics. Variables in each category proved to be significant in explaining price variations among differing properties. Overall, a total of 47 variables in the study explained 79% of the variance in the prices of a large sample of properties for which sales data were available in New Haven, Connecticut. Similar results have been obtained in a number of other studies, such as Ridker and Henning [66]. This study is, however, somewhat less satisfactory in that data aggregated across census tracts was used. There thus appears to be fairly wide agreement on the necessity of including the types of variables discussed above as controls in property value studies, data permitting.

The identification of all variables which determine property values is extremely important since the omission of a relevant variable can have serious consequences if it is correlated with an external effect. If, for example, the correct specification of equation (2.1) is

$$v_i = \alpha + \beta_1 z_{i1} + \beta_2 z_{i2} + \varepsilon_i \qquad (3.2)$$

but we estimate instead

$$v_i = \alpha + \beta_1 z_{i1} + \varepsilon_i^* \qquad (3.3)$$

(i.e. the relevant variable z_{i2} is omitted), then it can be shown that

$$E(b_1) = \beta_1 + d_{21}\beta_2$$

where $E(b_1)$ is the expected value of the ordinary least squares estimate of β_1 from specification (3.3) and d_{21} is the least squares estimate of z_{i1} in the descriptive regression equation

$$z_{i2} = d_{20} + d_{21}z_{i1} + \mu_i$$

(For a good accessible discussion of omitted variables see Kmenta [35, pp. 792-96]). Thus if variable z_{i1} measures the external effect and z_{i2} is omitted, the measured effect of the externality on property values will be biased unless $d_{21} = 0$. The direction of the bias will depend on the sign of d_{21} and β_2. This result also generalizes to the case of more than two relevant independent variables.

A more controversial issue has been the inclusion of buyer or resident characteristics in the regression equations, by some investigators. In particular, Anderson and Crocker [2] have included a resident income variable in their regressions. They justify this by deriving the potential purchaser's offer function for housing, which gives the maximum price an individual would be willing to pay for a given property and obviously includes both the characteristics of the property and the income of the individual. They then note that this function determines the value of the property "...provided only that each household occupies the most expensive available property it is willing to buy, and that each property is occupied by that household willing to pay the highest price". They thus conclude that "...if the (regression) model is to be properly specified, income must be included as an explanatory variable in its own right" (Anderson and Crocker [2 , p. 173]).

This is, however, true only if the seller of a property always knows and receives the maximum price an individual is willing to pay. The purchaser of a property therefore never receives any consumer's surplus from the purchase. This would, however, be unlikely if a large number of essentially similar properties are available in the market, as is usually the case,or if the buyer is as able a bargainer as the seller. In this case it is the valuation of the marginal buyers and sellers which determines the common price for the set of essentially similar properties.

The issue is thus obviously empirical and also very important, since the willingness to pay for the elimination of external effects is presumably also positively related to income. One would thus expect high income people to locate further from the source of the externality and pay more for their property due to, say, lower pollution levels, *ceteris paribus*. If the Anderson-Crocker model is correct, these properties would also be worth more since their owners had a higher income. The exclusion of an income variable would thus result in a upward bias in estimated pollution costs (see the discussion of omitted variables above).

If, on the other hand, the assumptions of the Anderson-Crocker model are incorrect, but income is nevertheless included, the estimate of pollution cost will not be efficient. More precisely (see Kmenta [35, pp. 396-399]), if equation (3.3) is correct but (3.2) is estimated instead, the sampling variance of the estimate of β_1 will be larger than it would have been with (3.3), unless z_{i1} and z_{i2} are uncorrelated. More empirical work on the role of individual income would thus be useful in the design of property value studies.

These same issues arise whenever variables that might or might not influence property values are considered. Exclusion of variables that should be included will result in biased estimates of pollution costs, while inclusion of variables that do not affect property values will lead to inefficient estimates of these costs. The latter problem is more acute in small samples than in large ones, where the loss of a few degrees of freedom is less serious.

While the role of individual income in the determination of property values is unclear, it may be sensible to employ neighborhood income as a proxy for the general amenity of a neighborhood. As we noted above, the general characteristics of other properties in a neighborhood may influence property values. For example, a mansion surrounded by other mansions is likely to be more valuable than an identical mansion surrounded by tract homes. If information about neighborhood characteristics is not available, neighborhood income may provide a reasonable proxy.

The use of property values as a price variable has also been questioned. Wieand [76] has suggested that the price of residential property is actually the product of the price of housing and the quantity of housing, both of which are unobservable. He then notes that the price of housing, and individuals' housing expenditures, need not be systematically related, suggesting that property values are inappropriate.

dependent variables in pollution studies. However, as Crocker [12] notes the issue turns on how the commodity housing is defined. If all properties are regarded as being the same homogeneous commodity, differing only in certain dimensions, the approach outlined in (3.1) seems acceptable. There is also a problem in the Wieand approach in that his housing quantity variable is unobservable, and it is not obvious how a reasonable measure of his housing price is to be obtained. His use of land area as a proxy for housing quantity is not convincing, since the relationship between lot size and the quantity of housing (exclusive of the lot) may depend on a number of factors such as relative land and construction prices and tastes as well as total housing expenditures.

A functional form must also be specified for the relationship (3.1). Equations which are linear in the variables (See Havelicek, Richardson and Davies [28] for example), i.e.

$$v_i = \alpha_0 + \alpha_1 z_{i1} + \ldots\ldots + \alpha_k z_{ik} + u_i \qquad (3.4)$$

and linear in the logs of the variables (See Anderson and Crocker [2]), i.e.

$$\log v_i = \beta_0 + \beta_1 \log z_{i1} + \ldots\ldots + \beta_k \log z_{ik} + \varepsilon_i \quad (3.5)$$

have both been estimated. The model underlying specification (3.5) can also be written:

$$v_i = e^{\beta_0} z_{i1}^{\beta_1} z_{i2}^{\beta_2} \ldots z_{ik}^{\beta_k} e^{\varepsilon_i} \quad (3.6)$$

The double log specification (3.5) would appear to be preferrable on the basis of a priori considerations. The linear specification (3.4) constrains the marginal effects of a change in characteristics to be the same for all properties in the sample, regardless of age or other characteristics. For example, the imputed price of an additional bedroom (i.e. the coefficient of the bedroom variable) would have to be the same for a new, \$20,000, two bedroom house or a 40 year old four bedroom house selling for \$10,000. The double log specification, on the other hand, constrains the percentage difference in prices to be the same for identical percentage differences in characteristics. In this case all properties having 50 percent more bedrooms than other properties would carry the same percentage premium in price. The linear specification may be particularly inappropriate for certain measures of external effects. For example, if the externality variable is distance from a landfill, the linear specification would imply that the dollar cost of being 100 feet closer to the landfill is the same for a $10,000 house and a $100,000 house. The double log formulation also allows for the possibility of non-linearities in the way in which units of a characteristic enter into the value of a property. For example, the marginal effect of an additional bedroom on house value will decline as the number of bedrooms is increased if the coefficient of the bedroom variable is between 0 and 1. The double log functional form also allows some interaction between characteristics since the marginal value of characteristic k, for example, will depend on the levels of all other characteristics. In other words, differentiating v_i in (3.6) with respect to z_{ik} we obtain:

$$\frac{\partial v_i}{\partial z_{ik}} = \beta_k \beta_0 z_{i1}^{\beta_1} z_{i2}^{\beta_2}, \ldots, z_{ik}^{\beta_k - 1} = \beta_k \frac{vi}{z_{ik}}$$

This last result may, however, also be a shortcoming if there is considerable variation in the price of properties within the sample. It may, for example, be unreasonable to allow lot size to affect the marginal valuations of a garage. The double log specification should thus be used with care in cases where there are large variations in prices or characteristics within a sample. For a good discussion of ways in which individual characteristics should enter this model see Emerson [17]. Details on the specification used in particular studies are discussed in greater detail in the next part of this section.

The quality of some data available for land value studies has also been questioned. A study of Pittsburg by Davis and Wertz [13] concludes that assessed property values "... are not accurate proxies for market values." While this conclusion may or may not be valid for other jurisdictions, their results imply that care must be taken in the interpretation of studies using assessed property value as the dependent variable. In Chapter 6, below, both assessed and market values are employed, and some evidence of this problem is encountered.

Census data based on owner's valuations of their property have also been used in a number of studies. The reliability of such data has also been questioned. A 1954 study by Kish and Lansing [33] indicates that owner's valuations in the 1950 Survey of Consumer Finances varied substantially from those of professional appraisers. The errors tended to be offsetting, however, with a small ($350) upward bias in the owner's valuation. There is, however, no evidence on how the owner's or appraiser's valuations relate to actual market values. There is thus a substantial amount of uncertainty about the quality of estimated property value data. This suggests that actual market transactions data, which is compiled by multiple listings services in many areas, should be used when it is available.

A Survey of Selected Empirical Studies

We will consider next a number of studies of the determinants of property values, with special reference to the types of data used, special specification problems, and a summary of important results. We consider first studies which attempt to measure the impact of particular externalities on land values. We also discuss briefly a number of related studies on the determinants of the property values.

The impact of solid waste disposal sites on property values has been studied by Goldberg et. al. [21] and Havelicek, Richardson and Davies [28]. The study by Havelicek, Richardson and Davies was based on records from 182 single family dwellings sold during 1962-1970, obtained from the multiple listing service in Fort Wayne, Indiana. The homes are situated in the neighborhood of five solid waste disposal sites. The dependent variable used in their study was the sales price of the dwelling. The independent variables used were size of house in square feet, number of bedrooms and bathrooms, age of property, lot size, the outstanding amount of loan, a dummy variable for owner or tenant, the sale date, the number of degrees property is away from prevailing downwind direction, distance from nearest disposal site, and dummy variables for the disposal sites. A linear relationship between price and the variables mentioned above was used. The shortcomings of this specification were discussed above. Their empirical results show that the distance from the fill and the number of degrees away from the downwind have significant positive effects on the sale price. In other words, other things being equal, the further away from the fill the higher the value the property. Similarly, the further away from the downwind direction the higher the value of the property. Their models explain between 78 and 79 percent of the total variation in residential property prices.

The regression analysis in Goldberg et. al. analyzed residential property values in the vicinity of eight solid waste disposal sites - seven landfills and one open dump - located in California and Virginia. The property value data are based on assessors records. Other data were obtained from on-site visits and local records. The dependent variables used in the regressions were the increase in property values, with and without improvements, from 1964 to 1970. The price data were obtained for housing near the disposal sites and in comparison areas having similar characteristics. Independent variables were dummy variables representing the distance from disposal site, visibility of disposal site, ethnic composition of the area, elevation, type of disposal site, proximity of truck routes, and location (California or Virginia). A linear and log-linear relationship appears to have been estimated. The elevation, location, type of site, and truck route variables were significant. The distance and visibility variables were insignificant. Between 25 to 81 percent of the variation in the independent variables was explained by the regressions.

The interpretation of this study is, however, rather unclear. It is not obvious why changes in land value were chosen as the dependent variable, since there exists no theory which indicates that externalities should influence changes or rates of change in property values. For example, if the effect of an externality is to depress property values a constant percentage amount relative to the value of comparison properties, rates of change in property values will remain unaffected. Their results are thus not necessarily indicative of the presence or absence of external costs.

A number of studies have attempted to measure the effects of air pollution on property values. The study by Ridker and Henning [66] used median property values in census tracts in the St. Louis metropolitan area for the year 1960. The use of census tracts ignores the variation in property values and characteristics of a property within a tract. Furthermore, the values are owners' estimates of the property and may substantially differ from the market price. However, in the case of air pollution, the relevant data are generally available for neighborhoods rather than for individual houses. The authors therefore, chose to use average census tract data. The explanatory variables used were: median number of rooms in the census tract, percentage recently built, number of houses per mile (as a proxy for lot size), time zones depending on express bus travel time to the downtown area, dummy variables defining accessibility to highways, shopping centers and industrial areas, school quality, crime rates, number of persons per unit, the occupation raio giving the ratio of craftsmen, foremen, operatives and laborers to the total number of employed persons, percentage of non-white population, median farm income, and mean sulfur levels as a measure of air pollution. Ridker and Henning justified the use of occupation ratio as a measure of the homogeniety of the neighborhood, the hypothesis being that in general, people like to live in neighborhoods that are homogenous with respect to occupation and social classes. The functional forms used are linear for all variables except houses per mile, occupation ratio and percentage of non-white, all of which appear in a quadratic form also. The empirical results show that the air pollution variable was statistically significant in explaining property values. Higher sulfur concentration implies lower median value of properties. The independent variables together explained 87 to 94 percent of the variation in the median property values.

Anderson and Crocker [2] carried out a study of the effect of air pollution on residential property values in the St. Louis, Kansas City and Washington D.C. standard metropolitan statistical areas. Three alternative dependent variables were used in their study: median property values, median gross rent and median contract grants from census tracts. The independent variables were: percentage of non-whites, median family income, percentage of each tract's units more than 20 years old, percentage classified as dilapidated, distance from the central business district, median number of rooms per housing unit, sulfur dioxide concentrations in the air and suspended particulates. At least one of the pollution variables was significant in each of the regressions considered and of the right sign, i.e. high levels of air pollution implied lower property values, ceteris paribus. There were no significant coefficients of the wrong sign. The functional form used was double log. The models used explained 70 to 79 percent of the variation in the logarithm of median property values.

A 1971 study by Crocker [12] on property damage due to air pollution used data from 1,288 FHA insured single family residences in Chicago. He used several alternative dependent variables, namely sale price of the residence, FHA estimated market price, FHA evaluation price as defined by "the price the typical buyers would be warranted in paying for the property for long term use or investment", FHA estimated average yearly cost of maintaining the property, and annual property taxes as estimated by the FHA. In regressions explaining the median property values in census tracts the independent variables used were: median family income, average income, percentage black, crime rate, percentage of houses dilapidated, percentage non-white population, percentage of older houses, school quality, minimum, maximum and average particulate concentration and sulfur dioxide concentration. In regressions using individual house characteristics, such as the estimated price or annual maintainance cost,as the dependent variable the independent variables used were: lot size, area, number of stories, mortgage term, a dummy variable taking the value of one if the house had aluminum siding, distance to the central business district, distance to the lake, a dummy indicating whether the house is a frame house or not, age of the house, minimum, maximum and average particulates and sulfur dioxide concentrations. The functional form used was double log except for the dummy variables. The variation in the dependent variable explained by the regressions varied from 57 percent for maintainance cost to 80 percent for the value of the house. This study also found that there is a significant negative relation between price and the other dependent variables and concentration levels of air pollution.

Other studies, which are not described in detail here in order to conserve space, relating air pollution levels to property values include Wieand [76], Ridker [65 , Chs. 6,7], Peckham [61]. The results of Ridker [65] are also summarized in Nourse[56]. The only study which differs significantly from the studies discussed above is Ridker [65, Ch. 7]. He constructs two time series indexes of property values; one for a neighborhood in St. Louis which experienced a significant increase in pollution in 1962 and one for a comparable comparison neighborhood. He finds that the two indexes do appear to diverge after 1962, but no tests of significance are presented. Data for the period 1957-1965 were used in the comparison.

The empirical work relating levels of external effects to property values also includes studies of the impact of aircraft noise on property values. The most extensive study in this area is the one by Emerson [17]. It also summarizes other studies in this area. Emerson's study is based on individual data for approximately 250 residences in the south Minneapolis area, as obtained from the multiple listings service. The dependent variable is the sale price of the residences. A long list of independent variables includes lot size, area, garage space, number of bathrooms, number of floors, the number of built-in appliances, the number of fireplaces, the age of the house, distance to the commercial center, distance to school, dummy variables for corner lots, location on main street, proximity to bus routes, siding, carpeting and draperies, and view, neighborhood compatibility of residence as measured by the ratio of the price of the given residence to the average price of residences on the block, accessibility and proximity to freeways, the distance to the nearest open green space and finally a composite aircraft noise rating. The functional form used is generally double log except for the dummy variables. The results indicate that the aircraft nuisance variable was statistically significant, implying that the higher the nuisance level the lower the value of the property.

A less extensive study of aircraft nuisance is the one by Paik [58]. His sample consists of 162 cross-section observations, by census blocks, from the vicinity of Kennedy airport in New York in 1960. The median values of single family dwelling units was used as the dependent variable. The independent variables were the number of people, average number of houses, average number of single houses, number of non-white houses, number of persons per room, median income, accessibility, and finally, noise levels obtained from noise contours based on 1965 flight and operations information. In this study also, the noise coefficient was highly significant with a negative coefficient, indicating that the higher the levels of noise, the lower the median value of properties in that area. The only functional form used was a straight linear relation.

The effect of freeway traffic noise on residential property values and apartment rents has also been studied. The study by Colony [11] was based on 91 parcels of land in Toledo, Ohio. The dependent variable used was the 1965 estimated sale price expressed as a percentage of the 1951 estimated sale price. The independent variables were horizontal distance from the expressway center line to the nearest building corner, vertical distance from expressway pavement to lot grade, and sound levels interpolated from sound level contour maps. Since the study did not present any standard error for the regression coefficients, it's not possible to conclude whether or not the variables included in the regression are statistically significant. It should also be noted that their specification of the dependent variable is subject to the same qualifications as the specification of the dependent variables in the Goldberg et. al. [21] waste disposal site study discussed above.

The study by Towne and Associates [72] investigates the effect of freeway traffic noise on apartment rents. The independent variables used in their study were floor area, bedrooms, vacancy rate, noise during rush hour, non-rush hour and at night, distance to freeway route access as well as to the central business district and shopping center, the type of shopping center, distance to school and recreation areas, quality of the apartments, number of units in the building, air-conditioning, type of floor, and neighborhood characteristics. The study concluded that the effect of freeway noise on apartment rents was insignificant.

The impact of reservoirs on land values has also been investigated. Reservoirs presumably produce positive externalities in the form of recreation possibilities. A study by Knetsch [37] used the price per acre of individual land parcels near 11 of the Tennessee Valley Authority reservoirs, as the dependent variable. The list of independent variables includes the distance from the reservoir, the square of the distance, a topography index, a dummy variable which took the value one if the lot was directly overlooking the reservoir, the value of improvements, cost of development per acre, the average work week as obtained from U.S. Department of Labor data, driving time from nearby urban centers and total retail sales of nearby population centers. Total sales was used rather than population to reflect the differences in the standard of living that might be exhibited by different cities having the same population. The relationship estimated was linear. The results indicate that tracts with a lake frontage were generally more expensive than similar tracts without lake frontage. It was also found that the value of a property declined as the distance from the lake increased, but at a much lower rate.

Williams and Daniel [77] also investigated the relationship between land values and reservoirs. They studied properties located near the outskirts of Jackson City in Mississippi. As in the Knetsch study, the dependent variable was price per acre. The explanatory variables were the number of acres involved in the transaction, the percentage of open land, the accessibility of the land as measured by the type of road frontage, estimated distance of land from interstate highway, an index of farm real estate values in Mississippi, approximate distance of the land from the reservoir and a measure of the effect of growth in the northeast Jackson area. The results show that the distance to the reservoir has a significant negative effect on the price per acre. In other words, the further away from the reservoir, the less the value of the property.

The effect of local public school expenditures and their effects on house values has been studied by Pashigian [59]. He used the natural logarithm of the median value of an owner occupied house in 1970 as the dependent variable. The explanatory variables were 1970 assessed value per average daily attendence in school divided by average number of rooms, median number of rooms in owner occupied units in 1970, median family income in 1960, median years of education for persons older than 24 years in 1960, percent non-white in municipality in 1970, ratio of 1970 average daily attendance to the 1960 average daily attendance, a dummy variable for house value, current expenditures per average daily attendance in 1970, percentage of teachers with masters degree, student-teacher ratio, and average number of total years of experience of teachers. Except for the house value and current expenditure, the remaining independent variables were expressed in their natural logarithms. The study indicates that house value increases with rising expenditure per average daily attendances, is not significantly affected by the ratio of teachers with masters degrees to teachers with bachelors degrees, rises with decreases in the student-teacher ratio, and falls with increases in the number of years of experience of a given teacher. While the results of the study may be interesting, the formulation implicitly assumes that the direction of causation is from expenditure per student to property values. It is more plausible, however, to argue that expenditure per student should depend on the average property value, because it's the latter that determines the revenue to the government in the form of property taxes.

In a similar study, Oates [57] studied the effect of local taxes and expenditures on the median value of owner occupied dwellings in 53 New Jersey municipalities. Independent variables used were percentage of houses constructed since 1950, median family income, distance from Manhattan, annual expenditures per pupil in public schools, the effective property tax rate and percentage of poor families. The tax, expenditure, and distance from Manhattan variables were expressed in their natural logarithms. The remaining variables entered linearly. The equations were estimated by ordinary least squares and two stage least squares. The latter estimation procedure was used to allow for the possibility of simultaneous equation bias since, as was noted in our discussion of Pashigian [59], property values may also have an effect on expenditures and taxes. These variables are therefore regarded as being endogenous. The tax variable is significantly negative and the expenditure variable significantly positive in both regressions, indicating that higher taxes tend to depress property values and high public expenditures tend to increase property values, ceteris paribus. The regressions explained 93 percent of the variance in property values.

The use of land value or rent differentials as a measure of non-market effects has also been suggested, and in some cases applied, in a number of other areas. Mohring [50,51,52] suggests the use of and uses differentials in land values as a measure of the value of time saved due to transportation improvements. Other suggested applications include estimating the value of irrigation water (Milliman [48]), the value of parks (Hendon [29]), the benefits of urban renewal (Rothenberg [68, 69]), flood control benefits (Lind [43]), and the effects of one-way streets (Kennedy [31]). These studies are not discussed since they do not contain empirical analyses as detailed as those discussed above, or are entirely conceptual.

There are also a number of studies on land values which are not directly concerned with the measurement of particular externalities or program benefits. In addition to the study by Kain and Quigley [30] discussed in the first part of this section, there is a study by Downing [16] of factors affecting commercial land values. The independent variables used in the study are distance to the central business district, distance to the shopping center, traffic level on main street, the corner influence, population, median family income in the census tract, percentage of non-white, the average size of the lot, and a time trend. The functional form used was generally linear except for distance to the central business district and distance to the nearest regional shopping center. The distance, corner influence, median income, and zone 13 dummy variables were not statistically significant. All the other variables had statistically significant regression coefficients. The regressions explained about 44 percent of the variation in commercial land values.

Grether and Mieszkowski [22] studied the determinants of real estate values in the New Haven area using multiple listing data. They used a large number of detailed characteristics of a property. Their formulation includes age of the property in quadratic form. In a similar way, the lot size was entered the formulation in quadratic form. To capture the effect of time on property values, a time trend was expressed in an exponential form. The study also indicated the presence of heteroscadesticity, indicating larger variation associated with larger transactions. To correct for this, they divided each observation by the size of the house, thus transforming the independent variable to price per square foot.

There is also a study by King and Mieszkowksi [32] of rents in the New Haven area which includes the racial and sex characteristics of renters and the racial characteristics of the neighborhood in a large list of independent variables. These variables were significant in some cases, but it was not clear whether supply or demand effects were being estimated. The regressions explained 77-78 percent of the variation in rents in the sample.

Gillingham [20] studied the determinants of apartment rents in 10 major U.S. cities using up to 29 independent variables, relating to apartment, building and neighborhood characteristics. The dependent variable was natural logarithm of rents. Independent variables entered linearly. The regression explained 53-82 percent of the variation in rents.

The recent book by Harris [25] should also be cited. It appears to contain a number of relevant papers, but was received too late to be included here.

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CHAPTER IV

A SURVEY OF THE TECHNICAL ASPECTS OF SOLID WASTE EXTERNALITIES

A. INTRODUCTION

Although our report focuses on the measurement of externalities associated with solid waste through their effect on economic variables, this chapter summarizes what is known about their physical manifestations. We do not consider here those aspects which may affect economic variables but do not have measurable physical characteristics, such as the unsightliness of dumps. We do survey the literature with respect to both the qualitative nature and the magnitudes of those externalities connected with the transfer, processing, and disposal of solid wastes. We have attempted to be particularly thorough in establishing what is known about the externalities associated with sanitary landfills and dumps, particularly the adverse effects related to gas production, surface and groundwater pollution, and the propagation of vectors and vermin. We also note the apparent effects on these externalities of not meeting the requirements of a proper sanitary landfill. However, we discuss, at least briefly, all of the externalities of which we are aware.

An important reason for including this survey is that the more clearly the relevant "technology" is understood by an economic analyst, the more likely that the assumptions of a related model will be appropriate. This is true of not only the qualitative nature of the assumptions but also of the implicit assumptions which must be made, in any empirical study, about the quantitative importance of different factors. A second important reason is that the indirect methods of valuing externalities (using, for instance, property value data) discussed in the last two chapters rely heavily on the assumption of perfect knowledge. If an individual misperceives his environment, his economic activity will not correctly reflect changes in this environment. In the present context, the assumption of perfect knowledge requires all traders to be fully aware of all implications of all relevant physical externalities. For instance, both the disagreeable aspects of air pollution and its specific effects on health must be known by all traders. As was discussed earlier, if this assumption is clearly inappropriate, valuation of a particular externality must be done directly, and the investigator must have detailed knowledge of its physical effects.

Recognizing the multi-disciplinary nature of problems associated with solid waste disposal, we had occasion to consult diverse sources in our literature survey. We would like to acknowledge here the prompt and courteous assistance we received from MEDLINE literature searches obtained through the reference department of the UCSD Biomedical Library and from BIOLOGICAL ABSTRACTS, BIORESEARCH INDEX, and CHEMICAL ABSTRACTS searches provided via the Center for Information Services and the reference department of the UCSD Science and Engineering Library.

On most of the topics we discuss, one or more surveys of the literature already exist. This survey clearly does not attempt to comprehensively reproduce the extensive detail found in some of these. Rather, we have attempted to provide a survey which will be useful to economists or others who are not experts in the area. We go into greater detail on those questions which seem directly relevant to the economic analysis contained in the other chapters of the report.

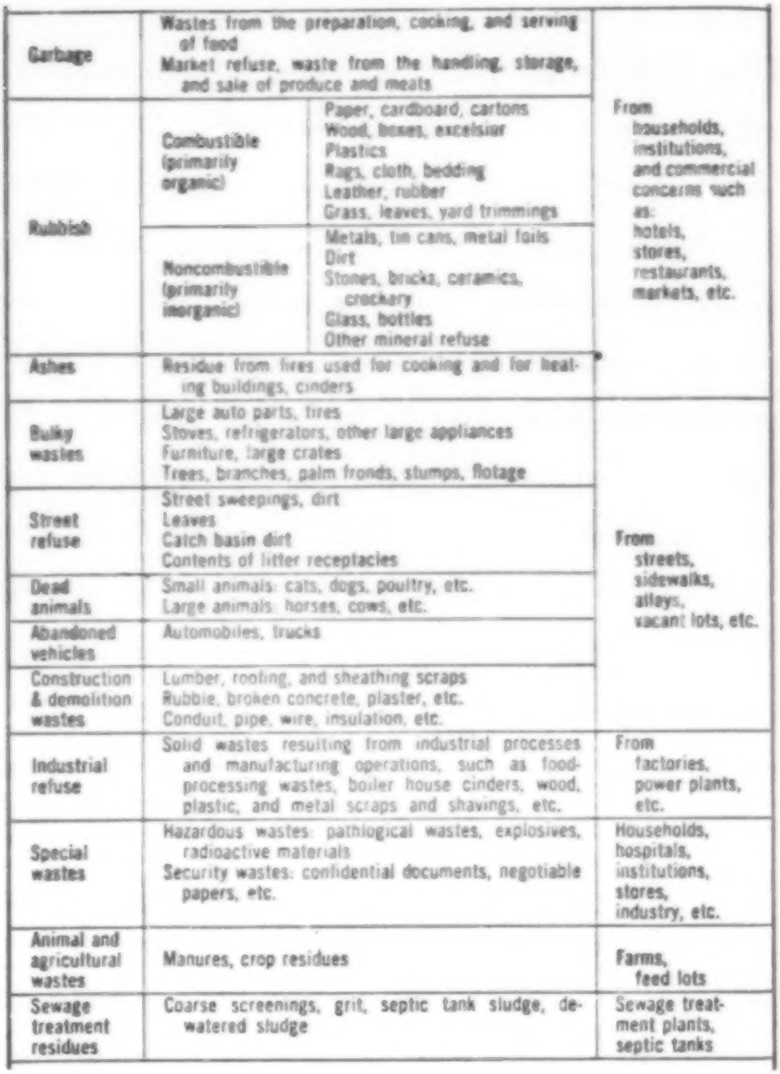
B. OVERVIEW

Definition of Solid Waste

Solid waste may be defined as any solid matter that is discarded or thrown away. The U.S. Environmental Protection Agency feels that the term solid waste should be defined to include: "garbage, refuse, and other discarded solid materials, including solid wastes, materials resulting from industrial, commercial, and agricultural activities, and from community activities" and should not include: "solids or dissolved material in domestic sewage or other significant pollutants in water resources, such as silt, dissolved or suspended solids in industrial wastewater effluents, dissolved materials in irrigation return flows or other common water pollutants" [135,p.20].

Table 4.1 [135, adapted from 44] presents a general classification of solid wastes. Although such a general classification includes dead animals, abandoned vehicles, and special wastes of many types, these account for only a minor portion of all solid wastes and generally must be handled with specialized procedures. Also, various types and quantities of industrial and agricultural wastes are managed by the waste producers themselves and do not enter general municipal solid waste management systems. In this report we shall concentrate on the bulk of solid wastes, namely the general refuse, garbage, and so forth which is usually collected by municipal agencies.

Table 4.1 GENERAL CLASSIFICATION OF SOLID WASTE MATERIALS



Garbage		Wastes from the preparation, cooking, and serving of food Market refuse, waste from the handling, storage, and sale of produce and meats	From households, institutions, and commercial concerns such as: hotels, stores, restaurants, markets, etc.
Rubbish	**Combustible (primarily organic)**	Paper, cardboard, cartons Wood, boxes, excelsior Plastics Rags, cloth, bedding Leather, rubber Grass, leaves, yard trimmings	
	Noncombustible (primarily inorganic)	Metals, tin cans, metal foils Dirt Stones, bricks, ceramics, crockery Glass, bottles Other mineral refuse	
Ashes		Residue from fires used for cooking and for heating buildings, cinders	
Bulky wastes		Large auto parts, tires Stoves, refrigerators, other large appliances Furniture, large crates Trees, branches, palm fronds, stumps, flotage	From streets, sidewalks, alleys, vacant lots, etc.
Street refuse		Street sweepings, dirt Leaves Catch basin dirt Contents of litter receptacles	
Dead animals		Small animals: cats, dogs, poultry, etc. Large animals: horses, cows, etc.	
Abandoned vehicles		Automobiles, trucks	
Construction & demolition wastes		Lumber, roofing, and sheathing scraps Rubble, broken concrete, plaster, etc. Conduit, pipe, wire, insulation, etc.	
Industrial refuse		Solid wastes resulting from industrial processes and manufacturing operations, such as food-processing wastes, boiler house cinders, wood, plastic, and metal scraps and shavings, etc.	From factories, power plants, etc.
Special wastes		Hazardous wastes: pathlogical wastes, explosives, radioactive materials Security wastes: confidential documents, negotiable papers, etc.	Households, hospitals, institutions, stores, industry, etc.
Animal and agricultural wastes		Manures, crop residues	Farms, feed lots
Sewage treatment residues		Coarse screenings, grit, septic tank sludge, dewatered sludge	Sewage treatment plants, septic tanks

Source: [135, p. 42]

Quantity

The quantity of municipal refuse generated annually in the U.S. is enormous. According to available estimates [16,144] a national average of 5.32 pounds of solid wastes per person per day was collected in 1967. Of this, approximately 3 lbs. is estimated to be domestic in origin, 1 lb. commercial, .59 lb. industrial, .18 lb. demolition and construction, and .55 lb. other [16]. Applying a conservative 4% annual increase in per capita generation to this figure yields a daily per capita collection figure of 7.0 pounds for 1974. Assuming a national population of about 210 million in 1974, this means that roughly 268 million tons of solid waste are collected annually. In an uncompacted state (density of 8-10 lbs/cubic foot) this quantity of wastes could easily cover the state of Delaware to a depth of one foot. But these figures exclude 10-15% of household and commercial wastes and 30-40% of industrail wastes that are self-collected and transported, as well as 3.1-3.7 billion tons of agricultural waste and crop residues, animal wastes, and mineral wastes [16,46].

Much less domestic refuse is generated in Europe than in the U.S. European domestic refuse generation has recently been estimated at 1.1-2.64 lbs/person/day

(.5-1.2 kg/person/day) [176,ref(3);93]. Solid waste authorities there, however, feel that the evolution of solid waste characteristics in Europe is similar to that of the U.S. but lags about 10 years behind.

Waste Management

This huge quantity of municipal refuse is subject to four stages in the management process: storage, collection and transportation, processing and final disposal. Many different techniques can be employed at each stage. For example, refuse in New York City may be stored in plastic bags, collected at the street curb, transported by compactor trucks to large multi-chamber incinerators for processing, and the incinerator residues finally dumped at sea. In rural areas, refuse may be stored in paper bags or metal cans, collected by an open truck, and transported to an open dump. Consequently, the environmental impact of the overall management system is radically affected by the particular management techniques which are employed.

It is also important to recognize that altering one or more techniques within the solid waste management system can produce effects not only internally--that is, on other components of the solid waste management system--but also on the related problems of managing our air and water resources. Encouraging the use of home garbage disposals may reduce the solid waste management system but increase the burden on the sewage system. Putting a tax on the solid waste generated by households may encourage people to burn much of their trash, which may be illegal but effectively impossible to control outside the cities. In many ways, there are clear connections among the management systems for solid, liquid, and gaseous wastes, and ideally all of these should be analyzed as one interrelated problem. In this report, we consider the direct external effects on water and air quality of solid waste techniques, but not the possible indirect effects.

General studies have been completed which survey present or planned solid waste management practices in the U.S. For the following areas see for example: California [2,31,159,160]; Fresno [4]; Kentucky [100]; New Orleans [187]; Oregon [139]; Pennsylvania [143]; San Francisco [35,158]; United States (national) [16,25,42,120,129, 130,131,132,135].

Storage

Refuse is usually stored in containers at its source prior to collection and transportation for various periods, depending on collection frequency. A substantial and increasing portion of household refuse, however, is being processed through garbage grinders, decreasing the amount of refuse stored at domestic sources and increasing the treatment burden of wastewater treatment facilities.

A variety of containers are used to store refuse. The choice of containers is influenced by factors of economy, socio-economic conditions, convenience, climate, and municipal regulations. The most common refuse container is undoubtably the familiar metal can, used either singly or in conjunction with paper or plastic bags [14,44]. Other containers receiving increased use in recent years, due to their advantages of convenience, increased collection efficiency, or improved sanitation are: paper bags, plastic bags, large metal bins, and special containers such as sealed paper bags prepared by home refuse compactors [161].

Collection and Transportation

In terms of employment and capital expenditures, refuse collection is by far the most important phase of solid waste management. It has been reported [16] that of the total management budget, 80% was spent on collection and 20% on processing and disposal. About 90% of municipal refuse is collected by crews of men working in conjunction with trucks. In 1968, 337,000 men were employed in the United States in collecting and transporting refuse, using 93,000 compactor trucks and 179,000 other collection vehicles to transport the refuse to disposal facilities. Both public and private agencies are involved in collection activities, with public services dominating in the collection of household wastes (51%) and private services dominating in commercial and industrial waste collection (62% and 57% respectively). Approximately 33% of the population lives in communities with separate collection systems in which garbage or rubbish must be separated for collection; the remaining 66% live in communities with combined collection systems or with both combined and separate systems. For combined collection systems 48% is collected once per week, 32% twice per week, and 20% at other frequencies. For separate systems, 61% of the material is collected once per week, 29% twice per week, 3% at other frequencies, and the remaining 7% of the garbage, although separated, is not collected.

Processing

After collection more than 90% of the municipal refuse is transported to final disposal facilities, primarily dumps and sanitary landfills; the other 10%

is processed. The goals of waste processing are volume reduction or the separation of waste components. Although commonly considered a final disposal method, incineration is actually a volume reduction technique. Typically, municipal refuse is reduced to 5-10% of its original volume and 20-25% of its original weight through incineration [45,50]. There were 289 community incinerators built between 1945 and 1965 in the U.S. As of December 31, 1966, there was a total installed daily refuse incineration capacity of 74,600 tons [42]. In contrast to other solid waste management facilities, 96% of these are publically owned.

Operating costs for refuse incinerators are quite high: $4-$6 per ton or higher compared to $.50-$1.25 per ton for most landfill disposal methods [1,16,26,129, 173]. Despite these high costs, incineration is quite common in metropolitan and other heavily populated areas because it requires much less land than dumping or sanitary landfilling of unprocessed refuse.

Many other waste processing techniques have been tried or are currently being used for demonstration projects of waste processing methods for the purpose of volume reduction or resource recovery. These methods include: various types of separation processes, chemical processing methods, mechanical densification and size reduction techniques, composting, and experimental resource recovery methods for metals, glass, and paper. Most of these processes have been rejected as financially or technically infeasible for widespread use, but research and development work continues on many techniques, notably pyrolysis, composting, baling, air classification, and gravity, mechanical, or magnetic separation. For information and further references on processing techniques the reader may consult, for example, Boettcher [18], Breidenbach [23], City of San Diego [165], Engdahl [64], Public Works [149], Wolf et al [198].

Final Disposal

The last step in solid waste management is final disposal of waste material. usually by sanitary landfilling or open dumping.

Sanitary landfilling is a specialized method of land disposal of solid wastes. A sanitary landfill is defined by the American Society of Civil Engineers as: "A method of disposing of refuse on land without creating nuisances or hazards to public health or safety, by utilizing the principles of engineering to confine the refuse to the smallest practical area, to reduce it to the smallest practical volume, and to cover it with a layer of earth at the conclusion of each day's operation, or at such more frequent intervals as may be necessary" [43]. Shorter and more explicit working definitions of a sanitary landfill include: "criteria for a site to be termed 'sanitary': (1) the site must have daily cover; (2) the site must not practice open burning; (3) the site must not have water pollution problems" [16]; and"...a process of dumping and compacting the solid wastes to the smallest practical volume and covering them daily with compacted earth in a systematic and sanitary manner" [159]. In any case, the basic operational characteristic of a sanitary landfill is the complete daily covering of all refuse with compacted earth. Specific operational and engineering techniques vary from site to site depending on such factors as site topography and hydrogeology, climate, available equipment, planned uses, and so forth. Generally speaking, refuse is dumped in a prepared portion of the site; it is spread in thin layers and compacted by heavy equipment, usually specially equipped buldozers or tractors. The compacted refuse is covered daily or more frequently, if necessary, with earth. The earth layer is compacted daily.

Land disposal sites which do not meet all of the criteria for sanitary landfills are classified as open dumps. Naturally, this subsumes a wide variety of land disposal practices, ranging from uncontrolled, open burning dumps to landfill sites which do not receive a daily earth cover but otherwise meet the requirements for a sanitary landfill or which have minor water pollution problems. In discussing dumping we will use the term "open dump" as described below and will explicitly consider those sanitary landfills which do not meet all criteria.

Open dumps may be easily distinguished from sanitary landfills. An open dump is simply a plot of land, frequently a ravine, natural depression, marshland or other site, either privately or publicly owned, where refuse is dumped in either a controlled or uncontrolled manner. At an open dump, no refuse compaction or earth cover is provided by bulldozers or tractors. Refuse is left above ground to decompose indefinitely; pollution control and public health programs are often nonexistent or unenforced. In addition, open burning of refuse, an on-site volume reduction processing technique, is practiced at 70-80% of these sites [129].

The total number of authorized land disposal sites in the U.S. is variously estimated at 12,000-25,000 [16, 25]. There may be ten times as many unauthorized or "promiscuous" sites [126]. Of the authorized sites, only 6% meet the requirements of a sanitary landfill. About 79% of all land disposal sites are publicly operated and approximately 63% are publicly owned [16].

Ocean dumping is a final disposal method which is also used for a wide assortment of solid wastes. However, ocean dumping of raw municipal refuse from U.S. coastal cities is no longer practiced. Although ocean disposal of municipal incinerator residues has been discussed, the quantity of this municipal waste, if any, which is currently being dumped in the sea is difficult to determine from available information. It is important to note that a substantial proportion of solid wastes bypasses some or all of these phases. This proportion includes wastes which are transported to disposal sites by individuals, industrial wastes disposed of in separate company owned facilities, and domestic refuse that is burned in backyard incinerators. It also includes litter which is carelessly discarded along highways or in vacant lots.

As mentioned above, the techniques which are employed for solid waste management have a radical influence on the environmental impact of the management system. There is considerable variation in the sequence of storage, collection, processing, and final disposal techniques used in the U.S., both among regions and states and even parts of the same state. For example, in the 1968 National Survey of Community Solid Waste Practices [129], region II (New York, New Jersey, Pennsylvania) reported a total of 226 incinerators, while region VIII (Montana, Idaho, Wyoming, Colorado, and Utah) reported no incinerators at all.

In region I (Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, Maine), routine uncontrolled burning was reported at 6% of its land disposal sites, while in region VI (North Dakota, South Dakota, Nebraska, Kansas, Missouri, Iowa, Minnesota), routine uncontrolled burning was reported at 65% of its land disposal sites [129].

In region I, 48% of all land disposal sites were classified as sanitary landfills, while in region VI, only 28% of all land disposal sites were classified as sanitary landfills [129].

Refuse Composition

The composition of municipal refuse is also an important factor in determining the environmental effects of solid waste disposal. National figures indicate that refuse composition has changed substantially over recent years and will continue to change. Table 4.2 [136] provides an estimate of the current composition on an "as-discarded" basis for seasonal, semi-seasonal, and non-seasonal states. Table 4.3 [136] shows projected refuse compositions up to the year 2000. These projections indicate several important trends.

The fraction of glass in refuse is not expected to change significantly over the next 30 years. This projection may be high if low-cost food and beverage plastic containers are developed, especially if these containers are degradable.

The metal content of refuse may decline slightly in the next 30 years. As with glass, changes in packaging technology could also cause a much stronger decline than anticipated.

The percentage of paper, cardboard, and other wood-fiber components in refuse will continue to increase by the year 2000. Paper products may account for more than one-half of refuse by weight on an "as-discarded" basis. Since the per capita rate of refuse generation, expressed in pounds/person/day, is steadily rising while the paper content of refuse, which decreases its bulk density, is increasing, the storage, collection, and disposal problems will become increasingly severe.

Table 4.2 ESTIMATED ANNUAL AVERAGE COMPOSITION OF 1968 MUNICIPAL REFUSE ON "AS-DISCARDED" BASIS (by percent)

Category	Un-Seasonal State (e.g., Florida)	Semi-Seasonal State (e.g., Alabama)	Seasonal State (e.g., Massachusetts)
Glass	7.6	8.1	8.8
Metal	7.5	8.1	8.7
Paper	32.6	35.1	38.2
Plastics	1.0	1.1	1.1
Leather,rubber	1.3	1.4	1.5
Textiles	1.8	1.9	2.0
Wood	2.3	2.4	2.7
Food wastes	18.2	19.5	21.1
Yard wastes	26.1	20.7	14.1
Miscellaneous	1.6	1.7	1.8

Source: [136,p.13]

Table 4.3 PROJECTED REFUSE COMPOSITION
(by percent)*

Refuse Category	1968			1970			1975		
	Seasonal	Semi-Seasonal	Non Seasonal	Seasonal	Semi-Season al	Non Seasonal	Seasonal	Semi-Seasonal	Non Seasonal
Glass	8.8	8.1	7.6	9.1	8.4	7.9	9.9	9.2	8.7
Metal	8.7	8.1	7.5	8.8	8.2	7.6	9.0	8.4	7.8
Paper	38.2	35.1	32.6	39.1	35.8	33.5	40.8	37.6	35.2
Plastics	1.1	1.1	1.0	1.3	1.3	1.1	1.9	1.8	1.7
Leather,rubber	1.5	1.4	1.3	1.5	1.4	1.3	1.5	1.4	1.3
Textiles	2.0	1.9	1.8	2.0	1.9	1.8	2.1	2.0	1.9
Wood	2.7	2.4	2.3	2.5	2.3	2.2	2.2	2.0	1.9
Food wastes	21.1	19.5	18.2	20.0	18.7	17.4	17.9	16.6	15.5
Miscellaneous	1.8	1.7	1.6	1.7	1.6	1.5	1.5	1.4	1.3
Yard Wastes	14.1	20.7	26.1	13.8	20.4	25.7	13.2	19.6	24.7
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

*Percentages shown are on an "as-discarded" basis.

Table 4.3 (continued). PROJECTED REFUSE COMPOSITION (by percent)*

Refuse Category	1980			1990			2000		
	Seasonal	Semi-Seasonal	Non Seasonal	Seasonal	Semi-Seasonal	Non Seasonal	Seasonal	Semi-Seasonal	Non Seasonal
Glass	10.3	9.6	9.0	9.5	8.9	8.4	8.1	7.6	7.2
Metal	9.4	8.7	8.1	9.0	8.4	7.9	7.4	6.9	6.5
Paper	41.5	38.4	36.1	45.0	41.7	39.3	49.7	46.0	43.5
Plastics	2.8	2.7	2.5	3.5	3.5	3.1	4.2	4.2	3.8
Leather,rubber	1.5	1.4	1.3	1.5	1.4	1.3	1.6	1.5	1.4
Textiles	2.1	2.0	1.9	2.5	2.3	2.2	2.8	2.6	2.5
Wood	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2
Food wastes	16.2	15.0	14.1	14.0	13.1	12.3	12.1	11.4	10.7
Miscellaneous	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9
Yard wastes	12.9	19.2	24.1	12.2	18.1	23.0	11.8	17.6	22.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

*Percentages shown are on an "as-discarded" basis.

Source: [136,p.13]

Plastic concentrations in refuse are expected to increase over 400%. The major categories of thermoplastics which are expected to dominate this growth are polyolefins (primarily polyethylene), polyvinyl chloride, and polystyrene [115]. Due to their high molecular weight and hydrocarbon structure, combustion of these polymers in conventional incinerators is unsatisfactory when their concentration in refuse exceeds the current 1-2% level [83]. Such combustion results in clogged or melted firing grates, excessive heat generation, and evolution of noxious and toxic, incomplete and complete combustion products, such as HCl in the case of polyvinyl chloride [83]. The morphology (degree of crystallinity) and chemical structure of these polymers also renders them almost totally immune to biodegradation. The non-biodegradability of plastic wastes, and their relatively bulky nature and poor compactability, combine to make sanitary landfilling of these wastes less attractive as a final disposal technique [115]. Further more, the fire hazards of exposed land disposal of plastic wastes precludes open dumping as a safe method of final disposal. In view of these special disposal problems, such a dramatic increase in the plastic content of refuse may have a serious impact on the externalities of the management system.

Resource Recovery

As the total volume of solid wastes increases and its composition changes, traditional waste management techniques and facilities appear increasingly inadequate, especially in urban areas. An attractive way of "disposing" of solid waste materials is to recover its components for reuse or to find alternative uses for the waste materials themselves. Recovery of materials from wastes is being practiced in the U.S. on a substantial, but decreasing, scale, Table 4.4 presents the quantity of recovered materials in relation to total comsumption of those materials for nine selected categories in 1967 [149]. These figures refer both to materials recovered during production and materials recovered from wastes. The great bulk of the materials which are recovered from wastes are taken from highly concentrated material sources such as steel from scrap auto bodies and appliances, or newprint from old newspapers. In general, the portion of input materias derived from waste sources has been declining. For example, the recovery rate (percentage of a material's total supply derived from wastes) for paper fiber has declined from 23.1% in 1960 to 17.8% in 1969. Similarly, the recovery rate for rubber has dropped from 18% in 1968 to 9.5% in 1970; and the rate for iron and steel has fallen from 44.9% in 1949-53 period to 40.0% in the 1964-68 period [149]. The gradual decline in resource recovery reflects primarily the economically non-viability of recycling with present technology.

Although resource recovery from specific wastes is being practiced, economically feasible technology for the recovery of metal, glass, and wood-fiber components from municipal refuse is currently unavailable [48]. The biggest technical obstacles to recovery of refuse components are problems of classification and separation of components and of purification of the separate materials to acceptable levels. Naturally, the composition of refuse affects the possibilities of effective recovery. Projections which indicate increased paper content seem favorable to eventual development of fiber recovery processes, while decreasing metal content will certainly make metal recovery more difficult [136,48,74].

C. COLLECTION AND STORAGE OF MUNICIPAL REFUSE

The first stages in the management of municipal refuse are storage and collection. In the U.S. a variety of storage containers and collection systems are employed. Although comprehensive data on national collection practices is lacking, it appears that the

Table 4.4 RECYCLING OF MAJOR MATERIALS: 1967.

Material	Total Consumption (million tons)	Total Recycled (million tons)	Recycling as Percent of Consumption
Paper	53.110	10.124	19.0
Iron and Steel	105.900	33.100	31.2
Aluminum	4.009	.733	18.3
Copper	2.913	1.447	49.7
Lead	1.261	.625	49.6
Zinc	1.592	.201	12.6
Glass	12.820	.600	4.2
Textiles	5.672	.246	4.3
Rubber	3.943	1.032	26.2
Total	191.298	48.108	25.1

Source: [149]

most common storage and collection system is the familiar metal garbage can and the compactor truck with a muti-man crew [135,44].

Refuse storage and collection create both direct and indirect adverse effects. The direct adverse effects are the unsightliness and odor of storage containers and their contents and the noise, road congestion, and air pollution from collection activities. The propagation of various species of flies and rats which act as disease vectors and nuisances are indirect adverse effects.

Very little information or data is available on the extent of the direct adverse effects of storage and collection on a national basis. It is evident, however, that innovations in specific systems can substantially alter the extent and composition of these externalities.

Recent innovations in collection systems have been largely confined to increasing the capacity, compaction power and loading efficiency of collection trucks. The major impact of these improvements has been to lower collection time and the number of trips necessary on a particular route [145]. In turn, these have probably decreased externalities due to air pollution and congestion while they may have increased noise.

Another interesting innovation in collection systems is the development of satellite vehicle collection. These are small, 3 or 4 wheeled vehicles that shuttle between domestic refuse storage points and a packer truck which subsequently takes the refuse to a disposal site. These satellite vehicle systems are being used in 50 U.S. communities in areas where pick-up points are not at a curb or in an alley. One study [49] which evaluated these systems noted that packer trucks remained on main roads and that their mileage was reduced. This indicates decreased air pollution and road congestion. On the other hand, the study identified several potential hazards of satellite vehicle operation, including increased littering of collection areas, damage to dwelling unit property and excessive noise.

In the area of refuse storage, innovation in container design and operation can also reduce external effects. Plastic cans, plastic bags, and paper bags can reduce collection noise, speed collection operations and make routes more sightly. Home trash compactors reduce refuse volume and seal compacted refuse in odor tight bags.

The indirect adverse effects of storage and collection practices are the propagation and harborage of flies and rats in and around storage containers. The association of fly and rat populations with refuse storage and collection practices is well documented [13,14,24,37 refs (1-7,9-16,18),61,62,85 refs (150, 152,153,391), 114,119,141,164].

Commensual species of rats and flies are known vectors of a variety of agents pathegenic to humans. (For a thorough discussion of the vector activities of these species see "Vectors and Vermin" in Section F, below). Besides imposing external costs through disease transmission, these species, especially the house fly, Musca domestica, are a ubiquitous nuisance in domestic environments, particularly during the summer months, the peak fly breeding season.

The process of fly propagation in refuse containers is straightforward. Female flies enter the container and lay their eggs on a suitable organic medium. The larvae then feed on this material for several days and then crawl out of the container to burrow into the adjacent dry soil to pupate. After pupation is completed, the adult females emerge from the soil. A number of factors are important in regulating this process: the quantity of putrescible materials in the container, the ease of access into the container for egg-laying adults and the ease of departure of larvae, collection frequencies, and temperature.

Research on the relationship between refuse storage and collection and fly propagation has shown that:

1. If garbage grinders are used to reduce the garbage content of domestic refuse or if garbage is drained and securely wrapped in at least three thickness' of newspaper, that flies have very few suitable breeding media and that fly production is thus greatly reduced [37,114].

2. Containers which afford free movement of egg-laying adults and migrating larvae allow much larger fly populations to develop. An increase of four times or more can be expected [14,24,37,61,62,114].

3. Twice a week collection of refuse result in much lower fly migration and production at the refuse source [14,24,37,61,62].

4. During periods of high temperature, fly life cycles are considerably accelerated, resulting in higher fly production from all storage and collection systems [37,114].

Some quantitative idea of the impact of various collection and storage systems can be gained from Tables

4.5 and 4.6 [61,62].

Although many publications refer to the association of rats with the storage and collection of refuse, little qualitative work has been completed [See 119 and 13 for references]. Although it appears that refuse--particulary mis-managed, infrequently collected and inadequately stored refuse--is a major source of food for commensual rat species, it is unclear that it is a vital source. In other words, better management of refuse storage and collection is certainly necessary for elimination of dangerous rat population but may not be a sufficient condition. Even the elimination of human refuse and garbage would not necessarily have a significant effect on the rat population except possibly in inner-city areas.

D. INCINERATION

Refuse incineration is a volume reduction, waste processing technique that is widely practiced in many areas of the U.S. Incineration is the controlled combustion of waste materials with the oxygen in air to convert refuse into gaseous products and solid residues. Incinerators are generally designed to allow rapid and complete refuse combustion and efficient handling of all residues and combustion products.

The combustion within a refuse incinerator is a

Table 4.5 PERCENTAGES OF WEEKLY COLLECTIONS THAT CONTAINED 50 OR MORE FLY LARVAE DURING EIGHT WEEKS OF STUDY

Type of System	Week Ending:								Total period of study
	8/2	8/9	8/16	8/23	8/30	9/6	9/13	9/20	
once-a-week metal cans	65	60	65	50	35	50	30	42	50
once-a-week paper bags	25	20	22	15	22	25	2	17	19
twice-a-week metal cans	25	12	15	12	7	15	0	2	11
twice-a-week paper bags	12	5	12	5	2	2	2	2	5

Source: [61]

Table 4.6 NUMBER OF GARBAGE CONTAINERS FROM WHICH FLY LARVAE MIGRATING EXCEEDED 50

Type Unit	Week of Study									
	1	2	3	4	5	6	7	8	9	10
Twice-a-week[b]	3	5	9	3	6	3	7	1	3	2
Once-a-week[a]	14	16	20	19	18	19	17	9	11	9
Exposed bag[a]	10	3	5	9	7	8	9	3	3	1
Enclosed bag[a]	7	6	16	5	10	7	8	3	5	4

---

[a] Garbage collected once-a-week

[b] Garbage collected twice-a-week

Source: [62]

high temperature process. Heat released by combustion is partly stored in the combustion products and partly transferred to the incinerator walls and incoming fuel. If prompt fuel ignition and combustion occur with the correct proportion of fuel and air, combustion is relatively complete [45].

The major products of complete combustion of organic fuels are carbon dioxide, water, sulfur dioxide, and nitrogen. Some nitrogen is converted to its oxides, particularly nitric oxide, and some of the sulfur dioxide is converted to sulfur trioxide. A small portion of the metals present, such as iron and aluminum, may also be converted to their oxides [45]. Table 4.7 presents a composite analysis of average municipal refuse [176 from 96]. Considering the very low sulfur content of refuse and the low conversion rate of nitrogen to nitrogen oxides, the gaseous products of complete combustion seem to pose minor air pollution problems, if any. Furthermore, residues from these ideal combustion conditions would be completely sterile and totally free of combustibles, thus presenting minimal final disposal problems. However, the combustion conditions in actual refuse incinerators may be far from ideal.

Table 4.7 COMPOSITE ANALYSIS OF AVERAGE MUNICIPAL REFUSE, AS-RECEIVED BASIS

	Percent	Theoretical Combustion air, lb/lb refuse
Moisture	20.73	
Carbon	28.00	x11.53 = 3.2284
Hydrogen	3.50 (0.71)[a]	x34.34 = 0.2438
Oxygen	22.35	
Nitrogen	0.33	
Sulfur	0.16	x 4.29 = 0.0069
Noncombustible[b]	24.93	
Total	100.00	3.4791

Caloric value, Btu/lb: 4,917 as fired; 6,203 dry basis; 9,048 dry-ash-free basis

[a] The net hydrogen available for combustion (0.71 percent) equals the total hydrogen (3.50)

[b] Noncumbustibles: Ash, glass, ceramics, metals.

Source: [176 from 96]

The nature of refuse as a fuel is the primary reason for poor combustion conditions during incineration. Because of the physical and chemical variations in refuse, combustion proceeds unevenly in the fuel bed. Combustion air flows through the more permeable portions of the bed, while other portions are starved for air. Moisture content variations in refuse components exacerbate this problem. Steam flowing from high moisture content regions also tend to disturb the air flow. In addition, variations in heating values of the refuse can cause large temperature differences and difficulities in temperature control. These and other factors result in incomplete refuse combustion.

Incomplete combustion of refuse has substantial adverse effects: a greatly increased volume of noxious effluents, especially particulates, and undesirable residue composition. The emissions from refuse incinerators have been measured in field situations to determine the components of incinerator effluents and to investigate the effect of operating and design characteristics on emissions [21,69,73,103,137,138,146,148,162, 175,180,181,182,194,196,201]. See also the literature reviews by Wikstrom and Carotti [172] and the Air Pollution Control Office [7].

Particulate matter in incinerator effluents consist of smoke, soot, flyash, grit, dirt, carbonaceous flakes, aldehydes, organic acids, esters, fats, fatty materials, phenols, hydrocarbons, polynuclear hydrocarbons, and other organics. Particle size ranges from less than 5 microns to 200 microns and larger. Table 4.8 shows the size distribution of particles from large European refuse incinerators [176 taken from 27].

Table 4.8 THE SIZE DISTRIBUTION OF PARTICULATES FROM EUROPEAN INCINERATORS

Particle diameter, microns	Percent
< 5	11.1
< 7	21.7
<10	30.1
<14	40.2
<19	46.9
<27	55.1
<39	67.5
<59	90.5
>59	9.5

Actual particulate emissions at the furnace outlet from incinerators of various types and designs are presented in Table 4.9 [176 taken from 133]. Published data on the chemical composition of particulates is scarce. Table 4.10 gives the results of a chemical analysis of flyash samples from a New York incinerator [176 taken from 133].

Gaseous incinerator emissions, unlike particulates, are of minor importance as a source of air pollution at present. Major toxic components include: oxides of nitrogen; oxides of sulfur; aldehydes; hydrocarbons; and ammonia. Concentrations of these effluents are primarily affected by excess air and underfire air during combustion. Excess air is the air supplied to burn the refuse in addition to that theoretically (stoichiometrically) necessary for complete combustion. Excess air is usually expressed as a percentage of the amount of air theoretically necessary for complete combustion, as "130 percent excess air". The furnace temperature of a refuse incinerator is usually controlled by adding excess air; the more excess air the lower the furnace temperature [176]. Underfire air is any air, controlled with respect to quantity and direction, that is supplied beneath the firing grate and that passes

Table 4.9 PARTICULATE EMISSIONS FROM MUNICIPAL INCINERATORS AT FURNACE OUTLET (corrected to 50 percent excess air)

Furnace type	Excess air percent	Underfire air, percent	Average dust loading lb/ton of charge
50-ton-per-day batch	235	20	0.78
50-ton-per-day batch	110	50	1.04
50-ton-per-day batch	100	70	1.79
250-ton-per-day continuous	190	20	3.8
250-ton-per-day continuous	180	50	2.8
250-ton-per-day continuous	150	100	4.6
250-ton-per-day continuous (traveling grate)	(6.0% CO_2)	41.8 scfm/sq ft grate area	12.4
250-ton-per-day continuous (reciprocating grate)	(5.0% CO_2)	105 scfm/sq ft grate area	25.1
120-ton-per-day continuous (rocking grate)	(7.0% CO_2)	17.5 scfm/sq ft grate area	9.1
150-ton-per-day continuous (rocking grate)	-	-	30.8

Source: [176 taken from 133, p. 83]

Table 4.10 CHEMICAL ANALYSIS OF INCINERATOR

FLYASH SAMPLES (percent by weight)

Component	Source of Sample		
	Upper flue	Expansion Chamber	Emitted
Organic	0.5	0.6	10.4
Inorganic	99.5	99.4	89.6
Silica as SiO_2	50.1	54.6	36.1
Iron as Fe_2O_3	5.3	6.0	4.2
Alumina as Al_2O_3	22.5	20.4	22.4
Calcium as CaO	7.9	7.8	8.6
Magnesium as MgO	1.8	1.9	2.1
Sulfur as SO_3	4.3	2.3	7.6
Sodium and potassium oxides	8.1	7.0	19.0

Source: [176, taken from 133, p. 84]

through the fuel bed [176].

Formaldehyde is only produced in minute amounts in municipal incinerators. For a 250-ton-per-day continuous feed incinerator operating at 185% excess air, .0014 pound of formaldehyde per ton of refuse was generated; for a 50-ton-per-day batch feed incinerator operating at 108% excess air, no formaldehyde was produced [84,179]. Hydrocarbon emissions are usually below the detectable level of measuring instruments. A 250-ton-per-day continuous feed incinerator using 150-190% excess air formed less than .08 pound hydrocarbon per pound of dry flue gas [179].

Because of the relative importance of particulate emissions from an air pollution standpoint, air pollution control equipment for incinerators has been designed primarily to remove particulate matter. A large variety of control devices have been developed toward this end. They include: settling chambers, in which large particles of flyash settle out of the flue gases immediately after leaving the combustion chamber; baffled collectors, in which large particles of flyash are removed changing the direction and/or reducing the velocity of the flue gases; scrubbers, in which flyash particles are removed by sprays or wet baffles; cyclone collectors which set up an intense vortex causing particles to be removed centrifugally; fabric filter collectors, in which particles are removed by filtering through long, tubular fabric bags; and electrostatic precipitators which collect particles by placing a charge on them by means of gaseous ions or electrons and then removing the particles at collecting electrodes of the opposite charge. These devices vary considerably in collection efficiency. Under one particular set of test conditions, the fabric filter collected from 97 to 99.9% of the dust measured by weight, the electrostatic precipitation collected from 90 to 97%, the scrubber collected from 80 to 96%, the mechanical collector from 30 to 80%, and the settling chamber up to 30%.

Nearly all municipal incinerators constructed since 1945 have some kind of pollution control equipment. A vast technical literature exists on the design and operating techniques of refuse incinerators and auxiliary air pollution control equipment. No attempt will be made here to survey these individual studies. The reader is referred to Corey [45] and Stear [176], for excellent treatments of these topics and further references. Stack emissions of particulates from incinerators with various control devices are listed in

Table 4.11 [176 taken from 92,179,192] and Table 4.12 [adapted from 1].

On a nationwide basis, municipal incineration is certainly a minor source of particulate emissions. If we assume that in 1968 approximately 200 million tons of municipal refuse were generated and that approximately 10% of this total was processed in municipal incinerators with an emission factor of 10 lbs. particulates per ton of refuse charged, then approximately 100,000 tons of particulates would have been emitted. For the same year, total particulate emissions in the U.S. were reported at 28.3 million tons per year [52]. This means municipal incineration contributed about .35% of total particulate emissions. Of course, its relative significance for a particular city might be much higher.

The same type of calculation can be applied to the other major categories of air pollutants sulfur dioxide, nitrogen oxides, and hydrocarbons. Assuming again that 20 million tons of refuse were incinerated and that SO_2, NO_x, and hydrocarbon emission factors are 2 lbs. per ton charged, 2 lbs/ton charged, and .3 lbs/ton charged respectively [60], total municipal incinerator emissions would have been 20,000 tons SO_2 per year, 20,000 tons NO_x per year, and 3000 tons hydrocarbons

Table 4.11 PARTICULATE LOADING OF INCINERATOR STACK GASES

Furnace type	Control Equipment	Excess air, percent	Underfire air, percent	Average dust loading, lb/ton charge in stack gases
50-ton-per-day batch	Scrubber	235	20	0.57
50-ton-per-day batch	Scrubber	110	50	0.55
50-ton-per-day batch	Scrubber	100	70	0.61
250-ton-per-day continuous (reciprocating grate)	Settling chamber and wet baffle	-	-	11.8
120-ton-per-day continuous (rocking grate)	Settling chamber and wet baffle	-	-	8.2
150-ton-per-day continuous (rocking grate)	Wet baffle	-	-	8.24

Source: [176 taken from 133, p. 84]

Table 4.12 PARTICULATE LOADING OF INCINERATOR STACK GASES

Furnace type	Control equipment	Excess air, percent	Average dust loading, lb/ton charge in stack gases
300 TPD-continuous (reciprocating grate)	scrubber	270	10.4
300 TPD-continuous (rocking grate)	scrubber	-	14.5
5-6 TPD-batch	scrubber and electrostatic precipitator	370	4.1
500 TPD-continuous (traveling grate)	scrubber	260	8.8
500 TPD-continuous (reciprocating grate)	scrubber	220	8.6
600 TPD-continuous (reciprocating grate)	scrubber	320	12.5
400 TPD-continuous (reciprocating grate)	multi-cyclone collectors and wet baffles	500	20.4

Source: [taken from 1]

per year. Nationwide emissions of SO_2, NO_x, and hydrocarbons for 1968 have been reported at 33.2 million tons, 20.6 million tons, and 32.0 million tons, respectively. Thus municipal incineration accounted for .06% of all SO_2 emissions, .1% of all NO_x emissions, and .009% of all hydrocarbon emissions.

The adverse effects of air pollution are well known. Air pollutants cause deleterious physiological effects in humans and animals, structural damage and soiling of affected vegetation, buildings and clothing, and visibility reduction. However, considering the minor role of municipal incinerators as air pollution sources, the incinerator externalities due to air pollution appear to be relatively small, unless marginal damage rates are considerably higher than average damage rates.

Further potential externalities due to refuse incineration are water pollution caused by discharge of process waters and leachate problems from land disposal of residue materials. Leaching problems associated with residue disposal will be treated in the following section.

Nearly all municipal incinerators utilize water for expansion chambers, cooling charging chutes, ash sluicing, quenching, conveying residues, and air pollution control [50]. The quantity of water required varies over a wide range according to incinerator design, but most plants use 1000-2000 gal. per ton of solid waste processed. However, if water is treated and recirculated, water consumption can often be reduced by 50 to 80%. Studies of incinerator wastewater show that it contains suspended solids, inorganic materials in solution, and occasional small concentrations of organic materials. Incinerator wastewaters are sufficiently polluted to pose a potential water pollution hazard if discharged indiscriminately to surface waters without prior treatment [116]. Suitable treatment methods for incinerator wastewaters include primary clarification, pH adjustment, and biological treatment [50]. Of course a convenient alternative, in some cases, to on-site treatment is discharge of wastewaters to a municipal sewage system. The 1968 National Survey of Community Solid Waste Practices [129] reports that 30.95% of incinerators surveyed needed wastewater effluent treatment and 27.43% provided such treatment.

E. SANITARY LANDFILLS

Sanitary landfilling, although perhaps the most apparently innocuous disposal method for solid wastes, may create a number of different externalities: noise, odor, gas generation, and ground and surface water pollution.

Noise

An almost totally neglected externality of sanitary landfilling is noise. Noise at sanitary landfill sites is generated by the unloading of refuse, including the operation of compactor and transport trucks as they disgorge their cargoes and the constant operation of the heavy equipment used for spreading, compacting, and covering the refuse. In order to achieve efficient operation and optimal compaction at medium to large capacity landfills, the heaviest and most powerful tractors, crawler tractors, steel wheel compactors, and draglines are employed. When all the heavy equipment at a medium to large sanitary landfill is operating, noise generation will be in the 80-120 dBa range [19,40].

Noise has both auditory and non-auditory adverse effects on exposed populations. Noise can interfere with speech communication [11,22,40]. Noise can cause a partial or permanent loss of auditory sensitivity [11, 22,40,41]. The non-auditory effects of noise exposure include: neural-hormonal stress response [11,22,79]; sleep interference [11,22]; task interference [11,22,79]; and mental stress and annoyance [11,22,40,79].

Noise from ground sources, such as landfill equipment, is attenuated by many factors before it reaches receivers. Foremost among these is wave divergence. The sound-pressure level generated by a sound source at a receiver decreases as a function of the distance from the source due to wave divergence. For hemispherical wave divergence over loss-free ground free of barriers, through a homogenous loss-free atmosphere, the sound-pressure level drops off 6 dB for each doubling of distance [105].

Other sources of attenuation due to environment conditions are:

1) attenuation due to ambient temperature and barometric pressure;
2) attenuation by absorption in the air;
3) attenuation by rain, sleet, snow or fog;
4) attenuation by barriers;
5) attenuation by grass, shrubbery, and trees;
6) attenuation due to wind and temperature gradients, atmospheric turbulence, and to the characteristics of the ground [105].

Any or all of these factors may affect the level of noise experienced by those near landfills.

Odor

As with noise and visual pollution, odor from land disposal of solid wastes has physical characteristics which are difficult to measure objectively. The two major obstacles to accurate measurement are specification of observer reaction to odors, and determination of odor emission factors and odor dispersion patterns. The problem of odor perception is quite complex. Odor is defined by the American Heritage Dictionary as "any sensation, stimulation, or perception of the sense of smell". The perception of an odor involves the olfactory detection of specific types or combinations of molecules present in the air. The exact mechanism of odor perception is a matter of considerable controversy. For further information concerning the mechanism of odor perception, the reader is referred to Amoore [8,9], Dravnieks [54], Friedman and Miller [75], McCartney [117], Russell and Hills [163], Theimer and McDaniel [190], and Wright [199]. One clear finding is that there is a pronounced variation in individual perception of odor thresholds and qualities. The authors of one paper [3 ref (100)] determined experimentally that materials in concentrations of 2 parts per billion or less have frequently yielded detectable odors. They state: "There is no such thing as a threshold odor for a community. Measuring the threshold odor for one man gives a number.

Measuring it for 5 men gives a range. If 200,000 people are used, a very wide range is obtained." From experimental evidence they reported that the most sensitive 5% of the population was at least 17 times as sensitive as the least sensitive 5%, and that the most sensitive observer in the 20-man panel in their experiment was on the average 11 times as sensitive as the least sensitive man.

A study of community odor surveillance by an observer corps of 120 high school students [89] concluded that: "The problem of precisely defining an offensive odor is difficult. An odor may be pleasant to one and offensive to another because of psychological associations with the odor. An objectionable odor can not be defined as one that is offensive to all individuals exposed to it since there will always be a few who will be blissfully unaware of even the most fetid stench." The authors go on to point out that psychological responses to a given odor vary among observers.

Intensity is only one factor of odor perception. A report on odor nuisance [6] states that " a strong chemical odor offends because of its intensity. Obnoxious or malodorous odors offend because of their 'quality'. The latter causes more complaints and tend to be odors originating from the handling and processing of organic compounds containing sulfur and nitrogen." The authors warn that odor emissions can cause "great personal discomfort, nausea, loss of appetite, loss of sleep, skin rash, psychic disorders, and eye, ear, nose, and throat irritation."

In addition to variation in odor perception, there are many environmental conditions which influence odor evaluation, dispersion, and persistence. Particularly important factors are wind speed and direction, vertical temperature gradients, temperature, humidity, and topography [89]. Naturally, the condition of the odor source itself, namely the putrescible and odorous portions of the refuse, will have a major influence on odor emissions and quality. The situation and exposed surface area of the odor source are primary determinants of odor emissions [87].

To obtain even an approximate measure of the quantitative and qualitative aspects of the odor nuisance caused by a surface source such as a landfill requires conbining analytic techniques related to odor evolution, transmission, and perception. This has proved to be a difficult undertaking. Proposals of methods to evaluate community odor problems have focused on survey techniques

[6,87,89]. Generally, such odor surveys employ a panel of odor evaluators or a corps of field observers to appraise odor samples in the laboratory or to make field observations in the community. Olfactory sensations are then classified according to simple verbal or numerical scales. These surveys provide valuable information on odor incidence but can not provide a satisfactory measure of the overall community impact of odor sources such as landfills. The importance of exposure time, odor fatigue, seasonal variation, and psychological response make long-term generalizations of survey results questionable.

Decay and putrefication of the putrescible portions of refuse and the exposure of odorous wastes releases objectionable air pollutants [6]. The extent to which this is true for municipal refuse placed in sanitary landfills is largely undocumented. Prompt covering of putrescible and odorous wastes is said to prevent the release of objectionable odors to the atmosphere [6]. However, a preliminary analysis of the land disposal investigation site data for regions 1 and 2 of the 1968 National Survey of Community Solid Waste Practices [130,132] indicates that approximately 10% of those sites with daily compacted earth covers required odor control programs compared to 24% of those sites which did not receive daily compacted earth covers, although the criterion of when a program is "required" is not clear. These statistics show that although odor problems are diminished by sanitary landfilling, they are not eliminated.

Gas Production

Another major type of external effect associated with sanitary landfills is the production of gases in the landfill. Many publications have dealt with gas production in sanitary landfills. See [30,76,123,124, 125,186,147] for comprehensive analyses of gas production from laboratory lysimeters and test cells; [12,26,58,59, 90,122] for descriptions of gas production problems at landfill sites; and [65,66,67,70,91] for particularly thorough theoretical treatments of gas generation and diffusion as well as measurements of gas compositions within landfills. Gas production by landfills can impose externalities in two ways:

1) causing fires or explosions in areas adjacent to or above the landfill due to a methane build-up; and
2) the pollution of groundwater due to solution of CO_2.

Groundwater pollution problems will be discussed in the following section. Before examining the problem of methane buildup a brief review of the mechanism of gas evolution and dispersion in a sanitary landfill is useful.

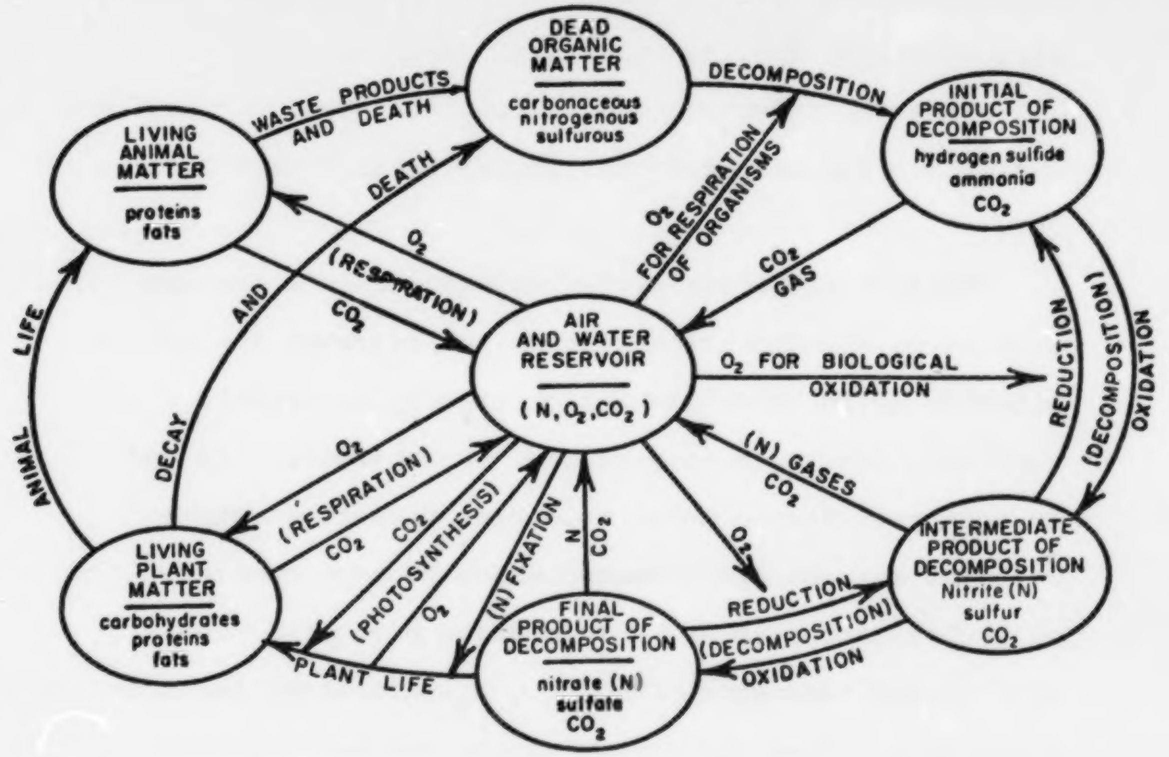
Gas production in a sanitary landfill is the result of the microbial decomposition of organic fill materials. The compostion of gases produced in the fill depends upon the composition of the organic materials and the quantity of oxygen present. If sufficient oxygen is present decomposition will generally be aerobic; if not, decomposition will generally be anaerobic; both may take place within a landfill simultaneously. Since oxygen is present immediately after sanitary landfills are completed all decomposition is initially aerobic.

The agents of aerobic decomposition are microorganisms known as aerobes. Aerobes are endemic to many aerobic environments such as soils, and comprise mesophilic and thermophilic bacteria, fungi, actinomycetes, and protozoa of many species [186]. In humid climates fungi are usually the primary agents while bacteria are more important in semi-arid locations. The addition of organic matter and oxygen to an aerobe environment increases the number of microorganisms dramatically and decomposition begins. Aerobic decomposition involves the progressive oxidation of organic matter by aerobes to produce CO_2 and H_2O and the oxidation of nitrogen and sulfur to nitrates and sulfates. Nitrogenous compounds are first oxidized to ammonia, then to nitrites, and finally to nitrates. Some production of nitrogen gas may occur. Sulfurous compounds are similarly oxidized to sulfates. Carbonaceous materials are completely broken down to CO_2 and H_2O [32].

Figure 4.1 depicts the carbon, nitrogen, and sulfur cycles for aerobic decomposition of organic materials [32].

Organic materials differ widely in their susceptibility to decomposition; sugars and starches are easily digested while cellulose and other complex organic compounds decompose very slowly. Furthermore, aerobes do not break down complex molecules directly; extracellular enzymes are excreted which convert complex molecules into simpler, intermediate products. These are finally reduced to CO_2, H_2O, N_2, nitrates, and sulfates [66]. When the oxygen supply becomes depleted from the demands of aerobic organisms and is not renewed by atmospheric infusion or dissolved O_2, aerobic bacteria cease to function and anaerobic processes take over. Anaerobic chemical reactions consist of the

Figure 4.1 AEROBIC DECOMPOSITION -
NITROGEN, CARBON, & SULFUR CYCLES


DEAD ORGANIC MATTER
carbonaceous
nitrogenous
sulfurous
WASTE PRODUCTS AND DEATH
DECOMPOSITION
LIVING ANIMAL MATTER
proteins
fats
INITIAL PRODUCT OF DECOMPOSITION
hydrogen sulfide
ammonia
CO_2
DEATH
O_2 FOR RESPIRATION OF ORGANISMS
O_2
(RESPIRATION)
CO_2
CO_2 GAS
AND
LIFE
AIR AND WATER RESERVOIR
(N, O_2, CO_2)
O_2 FOR BIOLOGICAL OXIDATION
REDUCTION
(DECOMPOSITION)
OXIDATION
ANIMAL
DECAY
O_2
(RESPIRATION)
(N) GASES
CO_2
CO_2
CO_2
(PHOTOSYNTHESIS)
O_2
(N) FIXATION
N
CO_2
O_2
LIVING PLANT MATTER
carbohydrates
proteins
fats
INTERMEDIATE PRODUCT OF DECOMPOSITION
Nitrite (N)
sulfur
CO_2
FINAL PRODUCT OF DECOMPOSITION
nitrate (N)
sulfate
CO_2
REDUCTION
(DECOMPOSITION)
OXIDATION
PLANT LIFE

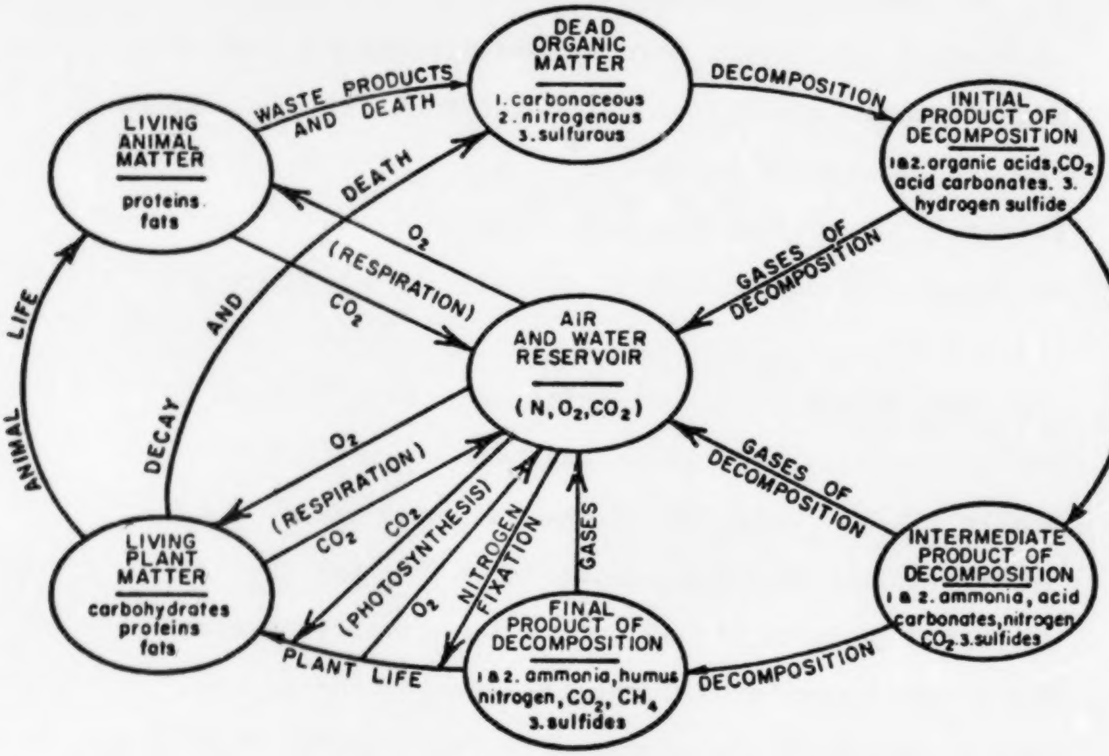
Source: [32, p. 20]

initial decomposition of organic compounds to organic acids, acid carbonates, CO_2 and H_2O. The organic compounds are further broken down to ammonia, nitrogen humus, carbon dioxide, methane, and sulfides. Figure 4.2 depicts the carbon, nitrogen, and sulfur cycles for anaerobic decomposition of organic matter.

A comparison of aerobic and anaerobic respiration shows that relatively more carbon dioxide is produced under aerobic conditions while methane, CH_4, is a major product of anaerobic conditions [32]. For excellent summaries of refuse decomposition the reader is referred to Hughes, Landon and Farvolden [91] and Engineering Science [65].

The volume and composition of gases produced in actual landfill situations has been a topic of considerable study. Over 90% of the gas produced by refuse decomposition in large landfills is CO_2 and CH_4 [67]. A typical pattern of gas generation usually develops for a newly completed landfill. During the initial aerobic stage, CO_2 production is very rapid. Peak concentrations of CO_2 are normally 75-98%, occurring one to seven weeks after the fill is completed [67,122,125]. As molecular oxygen supplies are exhausted, aerobic processes taper off, and CO_2 concentrations decline;

Figure 4.2 ANAEROBIC DECOMPOSITION - NITROGEN, CARBON, & SULFUR CYCLES


DEAD ORGANIC MATTER
1. carbonaceous
2. nitrogenous
3. sulfurous
DECOMPOSITION
INITIAL PRODUCT OF DECOMPOSITION
1&2. organic acids, CO2 acid carbonates. 3. hydrogen sulfide
WASTE PRODUCTS AND DEATH
LIVING ANIMAL MATTER
proteins fats
DEATH
O2
(RESPIRATION)
CO2
GASES OF DECOMPOSITION
AIR AND WATER RESERVOIR
(N, O2, CO2)
ANIMAL LIFE
DECAY AND
DECOMPOSITION
O2
(RESPIRATION)
CO2 CO2
(PHOTOSYNTHESIS)
O2
NITROGEN FIXATION
GASES
GASES OF DECOMPOSITION
LIVING PLANT MATTER
carbohydrates proteins fats
FINAL PRODUCT OF DECOMPOSITION
1&2. ammonia, humus nitrogen, CO2, CH4
3. sulfides
INTERMEDIATE PRODUCT OF DECOMPOSITION
1&2. ammonia, acid carbonates, nitrogen CO2 3. sulfides
PLANT LIFE
DECOMPOSITION

Source: [32, p.20]

methane concentrations gradually begin to rise.

Figure 4.3 [125] shows the gas concentration over time in a test landfill cell; Figure 4.4 [67] shows the gas concentration over time in a test landfill. From Figures 4.3 and 4.4 both the typical CO_2 "bloom" and the gradual CH_4 buildup can be noted.

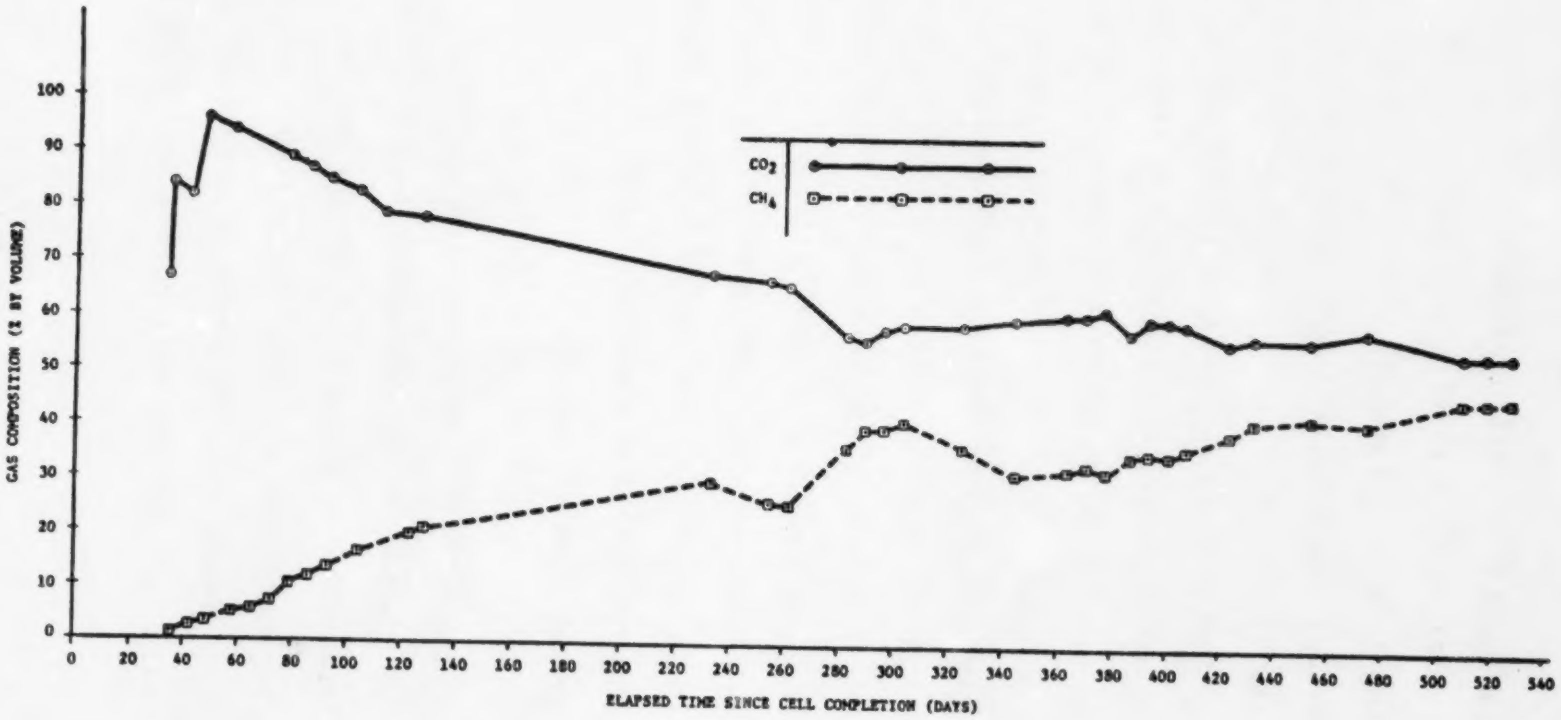
Gas movements through refuse and adjacent soil depends on gas pressure and density (concentration) gradients. The laminar movement of gases under pressure through a porous medium is governed by Darcy's law. Since the transfer area through which gases can flow from landfills into surrounding soils is relatively large and soils are usually quite permeable to gases, no large pressure differences are likely to develop. It is therefore permissable to treat gases as incompressible fluids when calculating flow rates. The proper form of Darcy's law is then:

$$v = - \frac{kg}{wg} \left(\text{grad } p\right)$$

where kg equals hydraulic conductivity, which depends on the medium through which the gas is flowing and the viscosity of the gas; wg equals the unit weight of the gas; and grad p equals the pressure gradient.

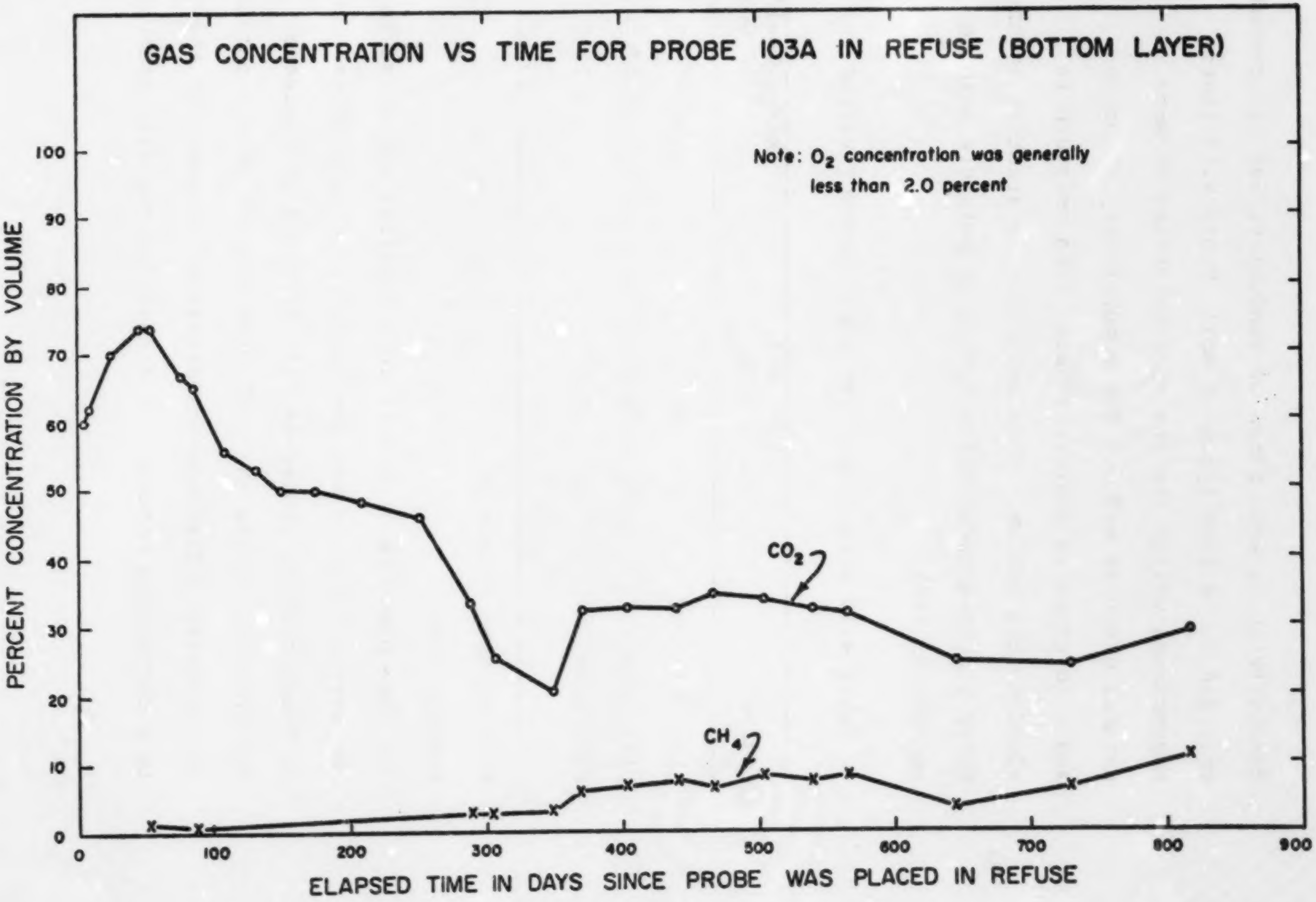
Because of the profound effect of the particle size distribution of a porous medium on its hydraulic

Figure 4.3 VARIATION IN GAS COMPOSITION WITH TIME IN CELL A FROM INVERTED COLLECTION CAN AT 13-FT DEPTH



Source: [125]

Figure 4.4 GAS CONCENTRATION OVER TIME AT A TEST SANITARY LANDFILL (bottom layer) Source: [67]



conductivity, a wide range of conductivities is commonly observed in various types of soil Table 4.13 lists approximate values for the conductivities of some natural granular media. The conductivity of porous media to gases is sharply reduced when moisture is added to the medium. This reduction is greatest in the finer textured media which have high moisture holding capacities [65].

Table 4.13 APPROXIMATE HYDRAULIC CONDUCTIVITIES

Medium	k(Water) ft/day	kg/wg(Gas)* ft^4/lb-day
Alluvial Sand	250	267
Silt Loam	1.0	1.07
Clay Loam	0.2	0.21

* Viscosity = .015 cp.

Source: [65]

Gas pressure gradients in a landfill can arise in two ways. First, a net production or uptake of gas by decomposition processes will increase or decrease the pressure inside the fill with respect to the outside air, causing a displacement pressure. Second, if there is a difference between the density of the fill gases and the outside air, a buoyancy pressure will develop due to gravity. The development of either displacement or buoyancy pressure will depend on the hydraulic conductivity of the bottom, sides, and cover of the landfill. It is assumed that the refuse itself will have a very high permeability and hence will not influence local pressure gradients, although this may not be the case if the landfill contains large amounts of fine material. It is apparent that the relative conductivities of the landfill boundaries are a major factor in determining the course of gas flow within a landfill. In addition, the rate of gas production may determine what portion of the gas is vented to the atmosphere or to the underlying strata.

During initial CO_2 blooms, experimental data has indicated horizontal diffusion velocities of 1-1.4 ft/day and downward vertical velocities of .8-1 ft/day. As the pressure gradient diminished, horizontal and vertical velocities decreased to .24 and .22 ft/day respectively [32,65,67].

The quantity of CO_2 and CH_4 produced by a landfill and, perhaps more important, the rate of gas production are closely related to several variables: the quantity, composition, and compaction of the refuse; the temperature and moisture content of the fill; the type of decomposition taking place; and the hydraulic characteristics of the fill boundaries [65,66,67,111,125,183]. Broadly speaking, the greater the quantity, putrescibility, moisture content and temperature of the refuse; the more loosely it is compacted; and the more porous the fill boundaries, the higher the rate of gas production within the landfill. It is important to note here, that although environmental or engineering techniques, such as the choice of a clayey cover material of low conductivity or the installation of gas underdrains, may effectively control the production rate and escape routes of landfill gases, the production of gases within the landfill after refuse emplacement is inevitable.

Table 4.14 [65] shows the variation in gas production from the decomposition of the three main types of organic materials found in refuse, carbohydrates, proteins, and fats, under aerobic and anerobic conditions at constant temperature and pressure. Though theoretical predictions of gas generation from landfills in the field are seldom accurate, the theoretical data in Table 4.14 serves to corroborate the general statements made earlier regarding the typical pattern of landfill gas production. Aerobic decomposition, which

Table 4.14 GAS PRODUCTION FROM ORGANIC SUBSTANCES

Type of Compound	Carbohydrate		Protein		Fat	
Composition, % by weight						
Carbon	45		53		77	
Hydrogen	6		7		12	
Oxygen	49		23		11	
Nitrogen	0		17		0	
Composition, atoms/atom C						
Carbon	1		1		1	
Hydrogen	1.67		1.58		1.89	
Oxygen	0.83		0.33		0.11	
Nitrogen	0		0.27		0	
Aerobic Respiration						
Production & Utilization/lb Compound	lb	cu ft	lb	cu ft	lb	cu ft
O_2 Uptake	1.20	14.5	1.46	17.6	2.92	35.2
CO_2 Produced	1.65	14.5	1.95	17.1	2.82	24.8
Net Uptake		0		0.5		10.4
Production & Utilization/lb Carbon						
O_2 Uptake	2.67	32.2	2.75	33.2	3.79	45.8
CO_2 Produced	3.67	32.2	3.67	32.2	3.67	35.2
Composition Exhaust Gas, % by Volume						
N_2		79		80		84
CO_2		21		20		16
Av. Molecular Weight		31.3		31.2		30.5
Anaerobic Respiration						
Gas Production/lb Compound						
CO_2	0.82	77.33	0.95	8.3	0.82	7.2
CH_4	0.30	7.3	0.36	8.8	0.72	17.6
Total Produced		14.6		17.1		24.8
Gas Production/lb Carbon						
CO_2	1.83	16.1	1.78	15.6	1.07	9.4
CH_4	0.67	16.1	0.69	16.6	0.94	22.8
Composition Exhaust Gas, % by Volume						
CO_2		50		49		29
CH_4		50		51		71
Av. Molecular Weight		30.0		29.7		24.2

Gas volumes at 1 atmosphere, 70° F.

Source: [65, p.50]

always predominates at first, results in large quantities of CO_2 produced per pound of organic material. Anaerobic decomposition processes, on the other hand, which take over after a period of weeks or months, lead to a reduction in CO_2 production and to the formation of CH_4, especially from fat decomposition. Since anaerobic decomposition usually proceeds more slowly than aerobic processes, CH_4 production can be expected over a considerable period of time.

The active life of a sanitary landfill is difficult to predict due to the many factors influencing the speed of decomposition. In colder climates, a landfill with a large non-putrescible content may decompose very slowly. Excavations through a completed landfill in North Dakota which had been undisturbed for more than 25 years revealed refuse items such as pictures in old catalogs and grocery sales slips that were still legible [20]. Using the total amount of carbon removed as a measure of the active life of a landfill, one study calculated that 50% of the initial carbon content of a test landfill in California would have been removed in 57 years and that 90% would have been removed only after 950 years [66].

The problems of fire and explosion hazards from landfills occur when methane gas, generated in the fill, seeps into enclosed areas such as adjacent sewer lines or the foundations of buildings located above the fill. The lower explosive limit (LEL) of a methane-air mixture is 5% methane. Methane seepage from completed landfills is both inevitable and sufficiently abundant to produce a significant hazard. At an experimental landfill it was calculated from field data that 24 times as much methane passed through the fill cover as went into the surrounding soil [66].

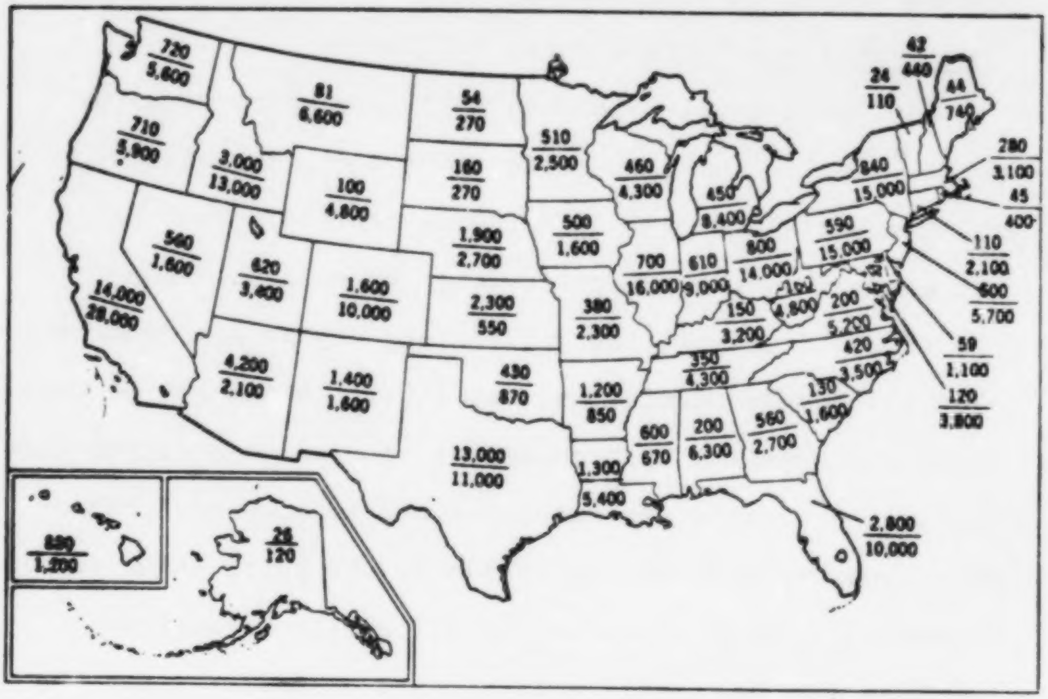
A long-term field study was conducted on gas seepage at a 29-building public housing development constructed over a completed sanitary landfill [70]. The composition and age of the fill varied considerably in different locations. In some areas filling had been recently completed with putrescible refuse while in other areas the fill contained relatively inert materials which had been filled many years earlier. A survey of the crawlspace atmosphere was begun 15 months after the foundations were poured. Combustible gases between 20 and 24% of the LEL were found in three of the buildings and concentrations between 10 and 20% were found in three others. Six months later, two buildings showed explosive mixtures, five showed concentrations in excess of 50% LEL and six others concentrations between 10 and 50% LEL. At this point mechanical ventilation with portable suction pumps of all the dangerous crawlspace was begun. During the second and third years methane seepage become so rapid in 5 of the buildings that automatic ventilation equipment was installed. Methane generation and seepage showed a definite seasonal variation, increasing in the early spring, peaking in July and August and tapering off during the fall and winter. It was postulated that higher underground temperatures stimulated microbial activity which increased gas production and the pressure of existing gas reservoirs against the floor slab. After 5 years gas seepage had ceased. Two explanations of this relatively short period of gas seepage were suggested. First, the age of the fill material may have been greater than assumed. Second, heat transmitted to the fill materials through the heavy underground concrete foundations of the tall apartment buildings may have speeded up bacterial action, especially during the colder months of the year, causing a large portion of the decomposition to be completed in a relatively short period of time [70].

Although very few instances of fires or explosions have been traced to methane seepage from landfills, the potential danger of such explosions is clear. Attempts to seal off the foundation slabs of the apartment building with asphalt and sodium silicate coatings proved unsuccessful. At other sites construction of special gas vents and underdrains have allowed controlled escape and burning of methane [58].

Groundwater and Surface Water Pollution

In 1965, total water use in the United States for public supply, rural domestic, livestock, irrigation, and industrial purposes (including thermoelectric power but excluding hydroeclectric power generation) was estimated at 310 billion gallons per day or approximately 1600 gallons per capita per day [134]. About 25% of this total was supplied by groundwater sources on a nation-wide basis. In certain key catchment areas, however, groundwater sources account for 40-80% of the total water supply. Moreover, in some river basins all available surface supplies are frequently utilized and groundwater must be withdrawn faster than it is recharged. Figure 4.5 shows total water withdrawal by states (excluding hydroelectric power) from groundwater sources and from surface water sources in million gallons per day in 1965 [134]. From Figure 4.5 it is evident that certain

Figure 4.5 TOTAL WATER WITHDRAWALS BY STATES (excluding hydroelectric power) FROM GROUNDWATER RESOURCES (upper number) AND FROM SURFACE WATER RESOURCES (lower number)
(in million gallons per day, 1965)


720
5,600
710
5,900
81
6,600
54
270
510
2,500
3,000
13,000
100
4,800
160
270
460
4,300
450
8,400
560
1,600
620
3,400
1,900
2,700
500
1,600
14,000
28,000
1,600
10,000
2,300
550
380
2,300
700
16,000
610
9,000
800
14,000
100
4,800
150
3,200
4,200
2,100
1,400
1,600
430
870
1,200
850
350
4,300
13,000
11,000
1,300
5,400
600
670
200
6,300
560
2,700
130
1,600
200
5,200
420
3,500
590
15,000
840
15,000
24
110
42
440
44
740
280
3,100
45
400
110
2,100
600
5,700
59
1,100
120
3,800
2,800
10,000
880
1,200
26
120

Source: [134]

states, particularly in the western U.S. rely heavily on groundwater supplies. By 1980, average daily withdrawals are expected to reach 600 billion gallons per day. Although a large portion of this increased demand will be met by re-use and reclammation of water, up to a 100% increase in the demand upon groundwater resources can be anticipated [72].

Ground and surface water pollution from sanitary landfills occurs through two different leaching processes. The first process is the solution of solid and liquid pollutants present in a landfill by excess water and their subsequent transportation out of the fill into surface or groundwater reservoirs. The second process is the solution of CO_2 in the groundwater adjacent to the fill and the consequent solution of minerals, mainly carbonates and bicarbonates resulting in excessive alkalinity and hardness.

Water quality can be defined as all the characteristics of water which affect its suitability for use. These include chemical, physical, and biological properties, specifically its organic, inorganic, and bacterial chemical content, taste, and odor [28]. Impairment of surface of groundwater quality due to leaching could be a major externality imposed by sanitary landfills.

These adverse effects take the form of decreased or total disutility of water for domestic, commercial, recreational, or public uses; or of direct and indirect deleterious effects on public health.

The generation and movements of contaminants in a sanitary landfill are dependent upon the content, spatial distribution and time variation of moisture in the fill materials [154]. This process of leachate generation and movement within the landfill takes place according to a water budget and the laws which govern moisture routing in porous materials [32,154]. In the soil cover, the uppermost layer of a landfill, moisture is usually added by precipitation and removed by runoff, evapotranspiration, and drainage. In the underlying areas, moisture is added by drainage from overlying layers or removed by evapotranspiration if roots penetrate to that depth. The hydraulic characteristics of the refuse layers in a sanitary landfill are similar to those of unsaturated, permeable soils. From the saturation point the soil drains rapidly at first and then at continually decreasing rates until, after two days, the drainage rate is small. The moisture content of the soil after the drainage rate has become small is known as the field capacity. When water is applied to a layer of soil at field capacity it drains rapidly to the underlying layers. After the moisture content has decreased to field capacity, the soil remains at approximately that moisture content, unless moisture is removed in other ways.

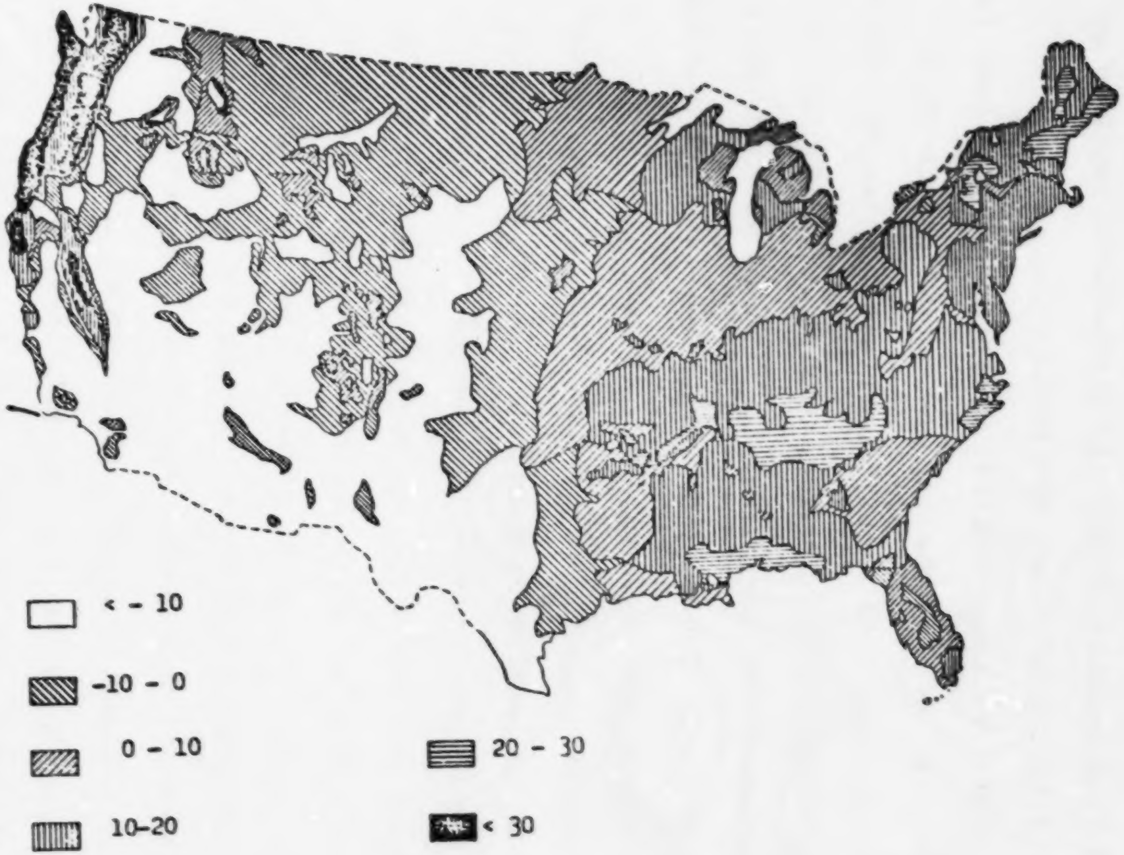
The moisture content of soil layers within the root zone of surface vegetation can be reduced considerably below field capacity by evapotranspiration. The moisture content of the soil at which no further water can be withdrawn by plant roots is known as the permanent wilting percentage.

As moisture is added to a soil below field capacity it does not distribute itself uniformly throughout the soil. Each layer must reach field capacity before significant quantities can drain to the underlying material. The mass of percolating water is preceeded by a wetting front or region of steep moisutre content gradient. The difference between a soil's field capacity and permanent wilting percentage is referred to as available water. After determining the available water storage capacity of each soil and refuse layer it is possible to apply the principle of continuity to moisture routing through sanitary landfills and associated materials [154].

The production of a leachate from a sanitary landfill is entirely dependent on sufficient net addition of water to the fill. The moisture required to bring various refuse samples to field capacity has been calculated at between 1.3-2.98 inches per foot of compacted refuse [154,65]. Thus for a 20' deep landfill, approximately 26"-60" of added moisture would be needed to bring the fill to field capacity. Figure 4.6 [76] is a map which shows areas of average annual potential moisture infiltration in the U.S. From the map it is evident that there is potential infiltration of water into landfills over a large part of the United States. As long as there is net infiltration leachate will eventually begin to be produced by a landfill. Indeed, by taking the infiltration and moisture storage figures from above it may be concluded that leachate production from a 20' thick landfill could begin in less than a year, in some areas.

The composition of leachate is primarily dependent on: the types and amounts of material in the fill material; the numerous supplemental variables controlling the type and speed of decomposition; leachate flow rate; and a number of interactions among the chemical processes taking place in the landfill. Solution of CO_2 and intermediate decomposition products and leachate flow rate

Figure 4.6 AVERAGE POTENTIAL INFILTRATION FOR THE U.S. (inches)


< - 10
-10 - 0
0 - 10
10-20
20 - 30
< 30

Source: [76, p. 125]

are major factors in determining leachate pH- which has a profound effect on the corrosive and solvent properties of the leachate. Leachates of low pH (below 5.5) are capable of greatly increased solubility of iron and iron salts, zinc, and lead.

Several comprehensive empirical studies have been completed on the quantity and quality of leachate produced, both in experimental and laboratory landfills, and actual field situations [30,32,65,76,91,111,150]. One summary of several of these chemical analyses is presented in Table 4.15. One study in which measurements were made from a laboratory sanitary landfill showed that most leachate components were being produced steadily or in increasing amounts after 600 days [76]. The analytic results show that leachate is a grossly polluted liquid which compares in dissolved inorganics with chemical plant wastes, compares in organic content with food-processing plant effluent, and may contain hazardous concentrations of trace elements and heavy metals [91]. Naturally, many other deleterious substances are undoubtedly present in landfills and can be leached into groundwater. These can include medicines, inflammable liquids, pesticides, insecticides, weed killers, and other toxic chemicals for domestic use as well as inadvertent or

Table 4.15 COMPARISON OF REFUSE LEACHATES WITH U.S. PUBLIC HEALTH SERVICE STANDARDS (in parts per million)

Substance	U.S. Public Health Service Standards[1] Group 1[2-3]	Group 11[4-5]	Blackwell[6]	LW5B Dupage[7]	LW6B Dupage[8]
Alkyl benzene sulfonate	0.5			0.72	0.30
Arsenic	0.01	0.05	4.31	<0.10	4.6
Chloride	250		1,697	1,330	135
Copper	1		0.05	< 0.05	< 0.05
Carbon chloroform extract	0.2				
Cyanide	0.01	0.2	0.024	< 0.005	0.02
Fluoride		3.4		2	0.31
Iron	0.3		5,500	6.3	0.6
Manganese	0.05		1.66	0.06	0.06
Nitrate	45		1.70	0.70	1.60
Phenols	0.001				
Sulfate	250		680	2	2
Total dissolved solids	500		19,144	6,794	1,198
Zinc	5			0.13	< 0.10
Barium		1	8.5	0.80	0.30
Cadmium		0.01	<0.05	< 0.05	< 0.05
Chromium (Cr^{+6})		0.05	0.20	0.15	< 0.05
Lead		0.05		0.50	0.50
Selenium		0.01	2.7	< 0.10	< 0.10
Silver		0.05	<0.1	< 0.1	< 0.1

Table 4.15 (cont.) COMPARISON OF REFUSE LEACHATES WITH U.S. PUBLIC HEALTH SERVICE STANDARDS (in parts per million)

Substance	U.S. Public Health Service Standards[1] Group 1[2-3]	Group 11[4-5]	Blackwell[6]	LW5B Dupage[7]	LW6B Dupage[8]
Ammonium					
Alkalinity (as $CaCO_3$)			3,255	4,159	1,011
Hardness (as $CaCO_3$)			7,830	2,200	540
Phosphate			6	1.20	8.90
Titanium					
Aluminum			2.20	0.10	0.90
Sodium			900	810	74
Hexane solubles			350	18	7
Biological oxygen demand 13			54,610	14,080	225
Chemical oxygen demand			39,680	8,000	40
pH			-	6.3	7.0

---

[1] U.S. Department of Health, Education, and Welfare (1962).
[2] Nitrates exceeding 45 ppm dangerous for infants.
[3] Should not be used if more suitable supplies available.
[4] Larger concentrations should be rejected.
[5] Fluoride is temperature dependent.
[6] Probably represents leachate from compaction and infiltration.
[7] Leachate from refuse about 6 years old.
[8] Leachate from refuse about 17 years old.
[9] Data provided by Metropolitan Sanitary District of Greater Chicago.
[10] Data from the files of the Illinois Department of Public Health.
[11] Rare earth and thorium production [Butler, (1965, p. 63)].
[12] Questionable values underlined.
[13] 20-day biological oxygen demand for leachate. Other values are 5-day B O D.

Source: [91, p. 114]

illegal deposits of industrial wastes, such as hexavalent chromium or cyanide. Normally one would expect to find only small quantities of these latter substances in leachate. However, if large, truckload size, deposits of these materials were placed in a landfill, special pollution hazards to groundwater supplies would develop [65]. The studies also show that leachate composition is highly variable across sites, and any generalizations may be unreliable.

The production of leachate is only the first step in groundwater pollution; several factors may mitigate or aggravate the pollution potential of a leachate source. As refuse leachate enters the ground and migrates through the underlying soil and rock layers, it is attenuated by ion exchange, dilution, dispersion, complexing, and filtration, and oxidation[91]. The extent of attenuation due to ion exchange is largely dependent on the type and texture of the subjacent materials and the chemical composition of the leachate and its pH. Clays are particularly active in ion exchange; the amount of exchange of a particular ion depending on 1) the type of clay involved; 2) the ions already present on the surface of the clays; 3) the other elements in solution and their concentration. The generally acid nature of leachate compounds the potential pollution problem because low pH values tend to reduce exchange capacities of renovating soils [76]. For a complete treatment of ion exchange on clay minerals the reader is referred to Grim [81,82].

The filtering action of subjacent materials is primarily a function of their texture. Fine-textured materials have a high capacity to retain dissolved solids and permit a low rate of groundwater movement due to their permeability. Coarser sands and gravels have less filtering capacity and allow higher rates of groundwater movement. British studies [see 91] established that by filtering refuse leachate through sand and gravel "general purification from organic matter can be effected under anaerobic conditions". Purification from chlorides, sulfates, and ammonia was found to be much less complete. For sites in northeast Illinois it was estimated that for leachate migrating through silty and clayey tills (heterogeneous mixtures of clay, sand, gravel and boulders), unfractured shales, and clays the total dissolved content would be reduced by one to two orders of magnitude in travelling a distance of 5 ft. An order of magnitude is a range of values between a designated lower value and an upper value ten times as large. Sands and silts would reduce total dissolved solids by one order of magnitude in 500 ft. and gravel and fractured rocks would be considerably less efficient [91]. Filtration of bacteria and other microorganisms in the subsurface is also closely related to texture; granular surfaces accomplish complete filtration in short distances while cracked or fissured material may permit greater travel.

The evaluation of the groundwater pollution hazard from any landfill site must take account of all the factors which influence hydrogeologic conditions in the subsurface; depth of the water table; permeability; flow gradients; distance to wells; geologic characteristics of the aquifer network, etc. [110]. At sites with relatively low capacities for ion exchange, complexing and filtering, pollution control must rely on dilution and dispersion of pollutants to acceptable levels before groundwater supplies reach points of use. Theory and empirical work suggest that for refuse leachate flowing in a uniform aquifer, longitudinal dispersion has little effect on the concentration of pollutants appearing in downstream wells, except possibly at very great distances from the source. In non-uniform aquifers both longitudinal and transverse dispersion will be effective in diluting the pollutants. However, any calculation on the probable degradation of groundwater supplies must consider the particular characteristics of the site, including the cones of influence of pumping wells [65].

Low travel velocities and diffusion rates can produce serious pollution problems. Pollution may not be noticed for years or decades. After the pollution is discovered the damage can not be repaired by simply stopping the source of contamination. With careful planning, however, groundwater pollution need not occur. For controlling pollution there are four possible objectives in landfill design: 1) elimination of leachate production; 2) migration of leachate under acceptable conditions; 3) recovery of leachate after migration; 4) retention and recovery of leachate. These objectives can be accomplished using standard engineering techniques such as grading, drainage construction and pumping, etc., if the hydrogeologic conditions of the site are properly understood.

Field study results of groundwater quality impairment due to leaching from sanitary landfills are also available for sites in California, Pennsylvania, Illinois, Wisconsin, South Dakota, and Texas [65,34,76,63,142,91, 193,10,166,118,99,72]. In addition to these, many publications have presented a more general discussion of various aspects of the problem of leaching from sanitary landfills [16,26,32,35,38,39,47,58,85,86,88, 90,107,108,109,110,113,129,130,132,135,140,151,153, 156,170,185,188,195,197,200,202].

Typically, the most concentrated pollutants observed at these sites are iron, nitrate (oxidized from ammonia and organic nitrogen), and hardness (an undesirable larger mineral content in water, particularly of carbonates and bicarbonates).

The second and perhaps more prevalent cause of groundwater pollution by sanitary landfills is carbon dioxide. As outlined above, CO_2 is a major product of both aerobic and anaerobic decomposition processes, and is produced in great quantities. Although the vast majority of the CO_2 produced is usually vented through the fill cover, a substantial quantity may migrate downwards until it contacts and dissolves in the groundwater reservoir. Recent evidence from sites in California indicates that for a 20' section of fill, vertical downward migration of CO_2 varied from 22,400-13,500 lbs/acre/yr. for several years. These quantities represented approximately 4-5% of the total CO_2 production in the fill [66,67]. Deep sampling wells revealed the presence of CO_2 production at depths up to 100 ft. below the refuse in homogenous sand and gravel soil. Moreover, if excess water is present within the fill CO_2 will dissolve there and aid in the further solution of pollutants by the leachate [65,66]. The three principle effects of CO_2 on groundwater are increased hardness, corrosivity, and acidity. These effects are functions of the relative quantities of CO_2, carbonates, and bicarbonates present in the groundwater and the water's pH.

CO_2 dissolves in water to form carbonic acid, H_2CO_3, which, in turn, reacts with otherwise insoluble or slightly soluble carbonates in soil and rock deposits to form soluble bicarbonates. As CO_2 is removed by the reaction more CO_2 is free to dissolve. This process continues until equilibrium is reached with the partial pressure of CO_2 in the atmosphere right above the water. This entire process of mineral solution can be reversed if the affected groundwater flows into a region where the soil atmosphere is low in CO_2. However, this process of reducing the mineral content in groundwater can take many years to complete [65]. California studies concluded that a sizable CO_2 concentration in the bottom layer of refuse can be expected for many years, with CO_2 passing into the ground. As usual, the pollution potential of any site depends on the particular environmental factors prevailing there. However, in general, it would seem that CO_2 poses the most serious threat to groundwater from landfills, since it is an inevitable product of refuse decomposition.

Excessive concentrations of carbonates, bicarbonates, and hydroxides cause alkalinity and hardness. Alkalinity, while not considered deleterious to human health, imparts an objectionable and unpalatable taste to water for domestic use. Furthermore, alkalinity is detrimental to many industrial processes, especially food and beverage production, which have recommended threshold values of 30 to 250 ppm [65,36]. Typical alkalinity values drawn from wells effected by the CO_2 production of nearby landfills range from 200 to 600 ppm.

Water hardness is caused by bivalent metallic ions (calcium, magnesium, and ferrous iron) which react with soap to form precipitates and impair cleaning action. In addition, water containing dissolved calcium and magnesium carbonates and bicarbonates will form a scale of calcium carbonates and magnesium hydroxides (temporary hardness) when evaporated or heated. Such scaling eventually deteriorates plumbing systems and their related components, such as hot water heaters. The maximum recommended hardness limits for domestic sources is 80 ppm [32]. Hardness values for affected wells may range up to 800 ppm.

Prominent examples of increased alkalinity and hardness in groundwater supplies have been documented [32 ref (4), 65,66,67] for sites in California.

As with pollution problems due to leaching, gas movement into groundwater supplies can be controlled by the application of the proper engineering techniques. Several types of drainage/ventilation schemes have been used successfully to control gas movement [32,59,66,67, 70]. Gas barriers and liners have also been developed, which can arrest or retard downward gas movement [32, 66,67].

Settlement

As mentioned above, landfills settle gradually as the fill materials undergo decomposition. A landfill may settle due to its own weight, the weight of the cover materials, the weight of any structure placed on it, or weight added to the fill by precipitation. The effect of settlement on the usefulness of a completed landfill site would not generally by considered an externality although, as we discuss in Chapter 5, its economic effects may be similar in some circumstances. Furthermore, settlement influences other externalities associated with landfills, particularly water pollution. We thus include a brief discussion of the problem of settlement.

There is little information concerning the engineering characteristics of sanitary landfills. From the few titles in the literature [101,112,121,174,183] several important facts are evident. Because of the extremely diverse nature of fill materials and the unpredictable extent of settlement, landfills are a particularly poor foundation material for construction. Fill materials have been noted for their erratic composition and extremely erratic, but low, densities [174]. This heterogenous composition and the low density and stability of fill materials creates severe foundation engineering problems, related to bearing capacity. If a building foundation is relatively small compared to the thickness of the soil cover of a landfill, the foundation may punch through the cover into the fill materials. Alternatively, if the foundation is somewhat larger and if the fill material is not greatly weaker than the soil cover, bearing failure may occur by rotation of a segment of the soil cover and fill materials. Estimates put the bearing capacity of a sanitary landfill at 500-800 lbs. per square ft. [174]. Such low bearing capacities may be circumvented, however, through several engineering techniques; foundation design; additional fill covers; and support piles or piers which extend through the entire fill. Naturally, foundations laid on support piles will be independent of landfill characteristics but their construction may be difficult.

Settlement problems are more persistent and possibly more serious than those of low bearing capacity. In general, landfills are subject to very irregular patterns of settlement. Different sectors or components of the fill may settle at very different rates. Although accurate and general data are lacking, limited information [121,125,189] suggests that sanitary landfills typically settle 10-30% or more of their original thickness. Since this settlement is not uniform, large surface depressions may appear in the fill cover. When water drains into these depressions, the rate of leachate production below them can be greatly increased. The water pollution problem may thus be much more severe than if settlement were uniform.

Leaching From Ash Landfills

Solid residues from municipal refuse incinerators are generally disposed of by landfilling. Like refuse landfills, residue landfills are potential groundwater and surface water pollution hazards. The same physical and environmental factors described above for refuse landfills govern leaching processes in residue landfills; the only major difference being the dissimilar composition of the fill materials. Very little research has been completed on the chemical, physical, and hydraulic characteristics of incinerator residues [98, 167]. Table 4.16 [176] presents the typical range of values for the various components of residue. Table 4.17 [1] presents the physical characteristics of residues from several types of incinerators. It is apparent from Tables 4.16 and 4.17 that incinerator residues and refuse have quite different physical compositions. One can only speculate how these differences affect the hydraulic characteristics of residues compared to refuse. Residues have quite low moisture contents, which might indicated high field capacities. On the other hand, the uniform, dense nature of residues and the large proportion of inert, non-absorbing components

Table 4.16 INCINERATOR RESIDUE COMPOSITION (percent)

Material	Range
Metals	19 to 30
Glass	9 to 44
Ceramics, stones	1 to 5
Clinkers	17 to 24
Ash[a]	14 to 16
Organic	1.5 to 9

[a] Exclusive of other material listed.

Source: [176,p. 98]

Table 4.17 INCINERATOR RESIDUE COMPOSITION

Incinerator	Moisture, as Sampled (%)	Heat, Dry Basis (Btu/lb)	Ash, Dry Basis (%)	Volatiles, Dry Basis (%)	Density, as Sampled (lb/yd^3)
A	15.0*	170	97.4	2.6	(†)
B	24.5	200	98.4	2.0	(†)
C	0.3	180	98.0	2.0	(†)
D±	-	-	-	-	-
E	21.8	520	97.0	3.0	1490
F	24.8	940	92.7	7.3	1620
G	10.5	70	99.4	0.6	1600

* Assumed.
† No measurement made.
± No laboratory analysis performed.

Source: [1]

point to extremely low field capacities. Because the exact hydraulic features of residue landfills remain unknown, it is difficult to predict leachate generation in field situations.

Preliminary information on the chemical composition of incinerator residues indicates that they contain about the same percentage of soluble material by weight as refuse but that most of the residue solubles are inorganic rather than organic. Leachates from residue landfills will reflect this predominance of inorganic constituents; in fact, one expects residue leachate to be similar to incinerator process water, with its high inorganic and low organic pollution loading. If the residue materials have a significant organic content, aerobic and anaerobic decomposition of these materials may occur, resulting in CO_2 generation [33]. Solution of this CO_2 in infiltrating waters, resulting in acidity, could increase the alkalinity and hardness value of the residue leachate. However, since the organic content of residues is usually quite low, CO_2 related pollution problems are much less severe for residue landfills than for refuse landfills.

F. OPEN DUMPS

Open dumping is certainly the most noisome method of solid waste disposal. Open dumping leads to: groundwater pollution; vermin and vector propagation; and air pollution due to open burning.

Noise

In general, noise problems due to dumps are less severe than those due to sanitary landfills since heavy machinery is not used in dumping operations. The primary noise sources at dumps are collection trucks and private vehicles discharging refuse. Thus the noise level at a dump will rarely exceed the 90-95 dBa level which is characteristic of large collection trucks operating at full power [19].

Odor

Malodor emissions are clearly much more severe for open dumps than for sanitary landfills. The source of malodors, the putrescible portion of municipal refuse, remains uncovered indefinitely at an open dump, thereby presenting the greatest opportunity for odor emissions. A survey of the site data from regions 1 and 2 [130, 132] of the 1968 National Survey of Community Solid Waste Practices revealed that about 50% of land disposal sites which received no cover were classified as needing an odor control program. As mentioned previously, only about 10% of all landfill sites in region 1 and 2 which received daily compacted earth cover were listed as needing an odor control program.

As cited in the earlier section on odors from landfills, the same factors of wind speed and direction, temperature, vertical temperature gradients, humidity, topography, and the condition of the odor source will be important in determining the emission, dispersion, and persistance of odors from dumps.

Unsightliness

Probably the most subjective and elusive externality imposed by open dumping of solid wastes is unsightliness. Unlike air, noise, or water pollution, unsightliness seems to have no readily measurable physical characteristics or parameters. Attempts to quantify unsightliness at land disposal sites have been made using surveys with small numbers of observers [4,130,132]. In the 1968 National Survey of Community Solid Waste Practices land disposal sites were classified as "sightly" or "unsightly" by field investigators. A tabulation of these site classifications showed that about 24% of those sites receiving a daily compacted earth cover were classified as unsightly. About 60% of those sites with other than a daily compacted earth cover were found unsightly, while 91% of those sites receiving no cover of any kind were judged unsightly. From these statistics, it is evident that the appearance of land disposal sites is greatly improved through the use of sanitary landfilling techniques.

Surface and Groundwater Pollution

Open dumps cause many of the same surface and groundwater pollution problems as sanitary landfills. Several instances of surface and groundwater impairment have been traced to leaching from open dump sites in California, Illinois, New York, and Great Britain [See 65 refs (32,33,46,66), 193]. Unfortunately, there are no comprehensive quantitative studies which deal specifically with water pollution problems from open dumps. However, the physical differences between dumps and landfills suggest that the water pollution effects may also differ.

At a typical open dump, refuse is simply dumped on top of the ground. No compacted earth cover is provided and vegetation rarely grows over the refuse.

These differences affect decomposition processes, gas production, and leaching.

Although decomposition becomes anaerobic in a sanitary landfill after several weeks, aerobic decomposition may continue indefinitely at an open dump, because of the opportunity for oxygen infiltration into the loosely piled, uncovered refuse. If refuse decomposition is aerobic, relatively more CO_2 and no CH_4 will be produced from the same quantity of refuse. In addition, since aerobic decomposition of refuse proceeds faster than anaerobic decomposition, the rate of CO_2 generation is greater. These factors will increase the hazards of CO_2 related groundwater pollution. Conversely, since dump refuse has no cover and a greater surface area than landfill refuse, gas evolution from dump refuse will be proportionally greater, thereby offsetting this increased gas production.

As in sanitary landfills, leaching from dumps depends on sufficient net addition of moisture. Since dump refuse is piled openly above the ground net moisture infiltration into dumps may be higher than landfill infiltration, since no moisture is removed by evapotranspiration from a soil cover. This may be offset by evaporation from the refuse itself. Leachate generation and quality are also affected by dump conditions. First, since dump refuse is not graded to afford good surface runoff, moisture infiltration in low-lying areas will be high. Second, little or no compaction of dump refuse means that the refuse will have a low field capacity, allowing high leachate flow. Leachate which percolates quickly through refuse can become more acidic than a slowly moving leachate. Acidic leachate has several corresponding adverse effects: increased leachate corrosivity, mineral solubility, and impairment of ion exchange capacities of renovating soils. Third, as leachates exit from the dump refuse only a proportion will enter the underlying soil layers. Because leachate production may be heavy during periods of heavy precipitation, surface water pollution may be cause by the resulting leachate runoff. Fourth, leachate which does enter subjacent soils may have a lower pollution load due to dillution. Finally, dumping does not require excavating large pits for refuse emplacement. Consequently, leachate pollutants may be more thoroughly attenuated in the thicker renovating soil layers which remain. This effect is particularly important at sites where the water table lies close to the surface.

In sum, then, it seems probable that groundwater pollution is decreased while surface water pollution is increased by using open dumping techniques.

Vectors and Vermin

A major externality of open dumping is the propagation of vectors and vermin at dumping sites. The principle vectors are various species of flies and rats. Dumps are important to these vectors as a food supply, breeding ground, and place of shelter.

The unequivocal relation of human disease to solid waste disposal methods, in this case open dumps, is not an easy task, however. In his excellent study of solid waste/disease relationships, Hanks [85] has stated five steps which must be satisfied to establish a firm solid waste/disease link:

1) discovery of harmful agents in the waste, or
2) demonstration that such agents develop within, or in association with, the wastes;
3) discovery of disease or other effects among the population which may reasonably be associated with these agents;
4) demonstration of the pathways by which the

effects are accomplished;

5) demonstration of the absence of effects following interruption of these pathways by one means or another, or their absence in populations not similarly exposed.

Flies represent a significant externality associated with open dumps, both as disease vectors and as nuisances. Sacca [164, p. 346] states:

> The dump constitutes a place of attraction for masses of adult flies which can permanently live, feed, and reproduce themselves on it. The production of new individuals is often huge there, owing to the abundance of larval food, made up of organic residues of vegetal and animal origin which have long fermented and are mixed with inert material (rags, waste paper, etc.) that help its aeration. During the favorable season, i.e., when the temperature allow the winged insects to fly, the dumps are a source from which masses of adult flies move toward human dwellings. The house flies often gather in the domestic environment in large numbers and are therefore important from the epidemiological viewpoint.

The literature contains many references on the importance of dumps for the production and maintenance of fly populations. See Hanks [85] for an excellent literature review. One source [169] estimates that 70,000 flies may be expected to propagate and emerge from one cubic foot of garbage.

Flies are firmly established as mechanical carriers of a large number of agents pathogenic to man [85]. The most important of these agents are viruses and bacteria. Some types of protozoa and worms, tri-trichomonas foetus, arthropods, and myasis are also carried by flies [164]. The following diseases have been linked to fly transmission: enteric diseases (typhoid, bacillary and amoebic dysentery, diarrheas, Asiatic cholera, helminth infections); myiasis, loiasis, onchocerciasis; Ozzard's filariasis; leichmaniasis; African sleeping sickness (trypanosomiasis); yaws; tylaremia; bartonellosis; catarrhal conjunctivitis; sandfly fever. Tentative additions to this list are: anthrax, salmonellosis, protozoal infestations, trachoma; poliomyelitis; tuberculosis; and hepatitis [85]. It is very likely that in areas in which flies have wide and prolonged access to concentrated sources of disease agents, especially human and animal feces, they will contribute significantly to human disease and mortality. However, in areas in which sanitation and personal hygiene standards are high in this regard, flies have little opportunity to transmit disease. Hanks concludes:

> Although much research is needed to clarify the role of flies even in those few diseases in which flies associated with solid wastes have been

> determined to be transmitters, the evidence overwhelmingly demonstrates that control of solid waste against breeding of domestic flies greatly limits their population. Present knowledge of the dynamics of disease transmission, exposure, dosage, etc., permits the conclusion that such limitation can contribute to the prevention of fly-borne disease [85, p.49].

Empirical studies have shown that a 6" daily compacted earth cover of the kind used to cover refuse in sanitary landfills can effectively prevent the emergence of flies [15,53]. On the other hand, effective fly control at open dumps is "difficult if not impossible" since fly larvae can be expected to emerge from all parts of the dump in enormous number, especially in the summer months [80]. While the exact proportion of the fly population which depends on open dumps is unknown, many studies speak of dumps as the major non-rural production source [85]. Consequently, replacing open dumps by sanitary landfills would greatly reduce the size of fly populations in human environments.

The other major disease vector associated with dumps is the rat. As with flies, rats have been implicated in the transmission of a number of diseases. These include: echinostomiasis; hemorrhagic septicemica; histoplasmosis; lymphocytic choriomeningitis; plague; rat-mite dermatitis; rat tapeworm infection; Rocky

Mountain spotted fever; salivary gland virus infection; salmonellosis; schistosomiasis; bilharziasis; sporothrichosis; swine erysipelas; trichinosis; leptospirosis; leichmaniasis; relapsing fever; tularemia; rickettsial pox; murine typhus; and perhaps other diseases [85].

However, a positive relation between dump maintained rat populations and increased incidence of any of the above diseases is difficult to establish. It is known that rats are extremely adaptable and have a prolific breeding capacity [85,119]. They can propagate in large numbers whereever food and harborage are available. It is also well known that rats are frequently attracted to refuse and are often found at open dumps and poorly operated landfills, yet open dumps and food wastes in general may have a very low marginal effect on the size of rat populations. Indeed, if open dumps were completely eliminated it is unlikely that this would significantly reduce rat populations, owing to the adaptability of the rat to other food sources and places of shelter, and the ready availability of these necessities in many domestic environments. The control of rat populations would require a coordinated program to systematically eliminate all possible food sources and shelter. Only in the context of such a comprehensive program would better solid waste management and the elimination of open dumping play a significant role in eliminating the externalities imposed by the commensual rat.

Open Burning

A final externality of open dumping relates to open burning. Open burning refers to the open combustion of refuse at a dump site, usually for the purpose of volume reduction. The refuse may be piled in a special area prior to combustion, or it may be ignited or catch fire spontaneously where it is first dumped. Of the sites sampled in the 1968 National Survey of Community Solid Waste Practices [129], it was found that 28% practiced "planned and limited" burning, and 48% practiced "uncontrolled" burning. The characteristics of open burning operations have been the subject of considerable discussion [See, for example 5,17,57, 128]. Open burning of refuse has a number of adverse effects: impairment of public health - especially deleterious effects on respiratory functions and eye irritation; visible air pollution plumes, decreased visibility, and esthetic complaints; soiling of the surrounding environment by fallout of partially burned carbonized organic matter; and local vegetation and structural damage due to aerosols from the combustion process [68]. The extent of these adverse effects is controlled by factors related to combustion, atmospheric conditions, length, and extent of human exposure, and the susceptability of the surrounding vegetation and structure to damage.

Open burning emissions are similar to those of municipal incinerators with no air pollution control devices. Table 4.18 gives emission factors for open burning of municipal refuse [52]:

Table 4.18 EMISSION FACTORS FOR OPEN
BURNING OF MUNICIPAL REFUSE
(pounds per ton of refuse)

Pollutant	
Particulate	16
Aldehydes (HCHO)	0.1
Hydrocarbons (hexane)	2
Nitrogen Oxides (NO_2)	2
Organic Acids (acetic)	13

Comparison of open burning emissions with these given earlier for municipal incineration shows that open burning results in significantly higher emissions of hydrocarbons, nitrogen oxides, and organic acids, and lower emissions of particulates and aldehydes. These emissions can be expected to vary, however, according to combustion conditions [52,56,68,78,94,104].

About 30% of all municipal refuse is processed by open burning [129]. Given the higher emission factors for open burning, and the impossibility of controlling these emissions, the absolute quantity of air pollutant emissions from open burning is much larger than total emissions from municipal incineration. Nevertheless, the contribution of open burning to national air pollutant emissions remains quite small. Hoffman [52] has estimated that in 1968 all solid waste disposal activities accounted for 1.1% of particulate emissions; .1% of sulfur oxide emissions; 5% of hydrocarbon emissions; and 1% of nitrogen oxide emissions on a national basis.

G. OCEAN DISPOSAL

A wide variety of solid wastes are disposed of in the oceans adjacent to the U.S. by surface dumping and through submarine outfalls. Information concerning current practices of refuse disposal in the ocean is quite limited [See 171 and 177]. Small scale ocean disposal of refuse takes place off the Pacific coast of the U.S. This refuse originates at military installations in Long Beach and San Diego and from a cannery in San Francisco. However, in the last 25 years there have been no sizable refuse disposal operations at sea. Several U.S. coastal cities had disposed of municipal refuse at sea prior to 1953 but this practice was discontinued because floating debris caused fouling of beaches which resulted in preventive legal action [171].

Aside from beach fouling, the adverse effects of ocean disposal of large amounts of raw refuse have yet to be investigated. It is probable that large scale ocean dumping of loose refuse causes severe ecological disruptions in the dumping zone, but these effects are merely speculative [171]. Indeed, it is possible that marine disposal of baled refuse may be favorable to the repopulation of overfished coastal zones by many species [191]. Research is currently underway to determine if artificial reefs made of baled refuse can provide beneficial habitats and food supplies for a variety of marine species [See 171].

In order to obtain an accurate understanding of the effects of ocean disposal of solid wastes, comprehensive research is needed in three areas:
1) baseline environmental data; 2) the fate of waste materials in the ocean ; and 3) the overall ecological effects of waste materials on the marine biota.

Before one can properly assess the effects of waste materials in the marine environment, it is essential to have an adequate understanding of the natural background biota fluctuations and the water mass characteristics that are normal for a particular region. Without this understanding it is impossible to distinguish normal variations from the effects of pollution. Broad-spectrum studies are also required to gather physical and chemical data on parameters such as temperature, salinity, etc., which are important determinants of marine biological processes [171].

At present, practical knowledge of how waste materials mix, disperse, degrade, and accumulate in resident species is very limited. Improved equipment and sampling procedures need to be developed and improved so that accurate predictive models of waste evolution in the sea can be obtained.

Finally, major research must be initiated to determine the long run effects of chronic pollutant concentrations on important species. Specifically, survival, reproduction, and behavior of these species must be observed in order to comprehend the probable long-term effects of pollutants on the dynamics of marine populations.

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CHAPTER V

PROBLEMS IN MEASURING THE EXTERNALITIES OF SOLID WASTE DISPOSAL

The physical manifestations of external effects related to solid waste disposal were surveyed in Chapter IV. The theoretical considerations relevant to measuring the social cost of these external effects and a survey of empirical attempts to measure them were discussed in previous chapters. In this chapter we consider some of the difficulties and practical problems of measurement within the context of solid waste, although many of these problems have general relevance.

As noted in Chapter III, there are two general methods of evaluating the social costs of external effects of some activity. The first will be termed the direct method, which actually consists of two stages. The direct method consists of, first, measuring directly the physical manifestations of the activity and, second, evaluating the social cost of these physical manifestations which is not already reflected in market activities. In measuring the external social costs of a sanitary landfill, for instance, the direct method would consist of measuring, in physical terms, the air pollution and groundwater pollution, if any, the noise generated, the added congestion and highway noise associated with the transportation system, and the visual effects of the landfill. (We discuss below the obvious difficulties in "physically" measuring such effects). With respect to an open dump, or to any landfill which does not meet all of the sanitary landfill standards, all of the effects mentioned above would have to be measured, but in addition one would have to physically measure the possible surfacewater pollution, the breeding of vermin and vectors, and the probability of fires and their expected physical damage. The knowledge of physical effects is not a sufficient basis on which to weigh their social costs. In order to translate these physical measurements into commensurate terms, the value which people place on the absence or extent of such physical effects must also be measured. Even if the measurement of the physical manifestations could be easily made, this translation into equivalent dollar values presents extreme difficulties.

Both the problems of physical measurement and of imputing values are finessed by the indirect method, in which the impact of the external effects of the activity on economic variables is measured. By measuring the impact of externalities on rents, or equivalently on the market values of surrounding real estate, the subjective valuation of the physical external effects is implicitly measured. Thus the indirect method provides a powerful tool by which extensive and difficult measurement and interpretation can be replaced with the generally manageable measurement of economic variables. However, there are two general difficulties with the indirect approach. The first is that the measurement of the effect of such externalities on land value requires that one has a model of the determination of the value of the relevant land and buildings, a model which is not just conceptual but operational. Developing and estimating the parameters of such a model is not a trivial task, as can be seen in Chapter VI, where such models are developed for "explaining" the value of land surrounding four sanitary landfills in Los Angeles County. The second general difficulty with the indirect approach is that the connection between land value and the evaluation of the social costs of the external effects is based on all the assumptions of the competitive model, some of which may be inappropriate.

The indirect method of measuring the external costs of sanitary landfills is applied in Chapter VI. The purposes are both to apply the method to this particular example and to advance the state of the art itself. In order to provide perspective on the relative merits of the indirect method of evaluation and on its validity, we discuss in this chapter the problems of applying the direct method and the limitations of the indirect method.

In applying the direct method of measurement, it is easy to commit a crucial error which we shall refer to as the "fallacy of ignoring adjustments". Suppose, in general, that a particular activity is imposing external costs on others. Those harmed by the activity will generally take steps to reduce the costs imposed upon them, and possibly to "eliminate" the cost. The proper comparison is obviously with and without the offending activity, and any costs borne by others due to the activity are external social costs, including the possible costs of their adjustments. Suppose, for instance, that a factory is built in a residential area which emits fumes of a particularly obnoxious character. Suppose that the fumes extend for a mile in all directions and that, as a result of the fumes, all residents choose to move elsewhere, leaving the affected area vacant. Suppose that outside of the affected circular area the fumes are harmless and disperse to insignificant levels. In such a case, a superficial application of the direct method of evaluation could lead to the conclusion that the fumes from the factory impose no costs on society, since an inspection of the area in which the fumes are physically present show that it is uninhabited. This is obviously fallacious; to an economist, the fallacy can be described as ignoring the opportunity cost of the land. With the factory, the land has, let us presume, no uses at all. Without the factory, it is useful as residential land. The fact that it cannot be used as residential land is a social cost of the factory, even if it is not a private cost. Obviously, if the factory is there first, before the development of the adjoining land, the restriction on the uses of the adjoining land still represents an opportunity cost, although one which would be less obvious than if vacant houses surrounded the factory.

In the simplified example above, the fallacy of inferring that no social cost exists because there is no one to smell the noxious fumes would be fairly obvious. However, the same fallacy would exist in a subtler form if, as a result of the factory, the adjoining land were used for some activity, say agriculture, which was not affected by the fumes but which would not be the best use of the adjoining land in the absence of the factory. The difference in the value of the land when used for agriculture as compared to its use as residential land, in this example, would still represent an opportunity cost and would represent the appropriate measure of the external cost involved. Similarly, if the adjoining land is nevertheless used as residential land but the residents are forced to air condition their homes, the cost of the air conditioning represents, at least in part, a social cost attributable to the factory activity. The complexity of measuring such costs in a practical situation is illustrated by this example, for it is likely that the houses with air conditioning would be preferable to the houses without air conditioning. Thus it would not be appropriate to attribute the entire cost of the air conditioning as an external cost of the factory operation. The question of how much of the air conditioning cost to allocate to the factory illustrates the beauty of the indirect approach to measuring externalities, for the proper answer is that the net cost should be attributed to the factory, where net refers to the subtraction of the increase in house value, attributable to air conditioning, from the cost of the air conditioning. In order to clarify this point, consider the following example. Suppose that the houses surrounding the factory are identical and would be worth the following amounts with and without the factory and with and without air conditioning:

Without factory, without air conditioning: $20,000
Without factory, with air conditioning: $22,000
With factory, without air conditioning: $17,000
With factory, with air conditioning: $21,000

Suppose that air conditioning costs $3,000 to install, purely for purposes of illustration. Then it is not in the interests of owners to install air conditioning, since it costs $3,000 and increases the value of the house by only $2,000. Obviously in a realistic situation, the residents might differ and some might choose, nevertheless, to install air conditioning, but we assume here that the housing market is a perfectly competitive one and therefore that a resident would never be led to make an improvement which is not "profitable".

Such an assumption is clearly not met exactly in the "real world"; we discuss the implications of that discrepancy below in the discussion of the indirect method of measurement.

With the factory in existence, air conditioning increases the value of the surrounding houses by $4,000; by the competitive assumption this implies that the residents value the change in consumption opportunities (fresher and cooler air) by $4,000. Thus the existence of the factory makes air conditioning preferable. However, it is clearly inappropriate to charge the total cost of the air conditioning, $3,000, as an external social cost against the factory; the house is worth more with the air conditioning and with the factory than it would be without either. In particular, it is worth $1,000 more with both than it was worth with neither, so it seems logical to attribute the "net cost" of ($3,000 - $1,000) = $2,000 as the external social cost imposed on the surrounding residences by the factory.

This imputation is not only logical, but is justified by the economics of the situation. In fact, under the conditions assumed, the value of the houses, without air conditioning, would be $18,000, and the decrease in the value of $2,000 reflects the social external cost. That is to say, the "value" of the house, without air conditioning, of $17,000, would not be an equilibrium market value. If the factory were to suddenly appear on the scene, the market value of the surrounding houses would not drop to $17,000, but only to $18,000, given the assumption that "information is perfect", and in particular the knowledge that the installation of air conditioning (at a cost of $3,000) would produce a house worth $21,000. The drop in value of $2,000 thus represents the fall in market value which results when "profitable" adjustments are perceived, which cost less than they add in value in the new situation.

The example shows very clearly the power of the "indirect" method of computing the external costs of some effect. If one simply looks at the attractiveness of the houses in the surrounding area before and after the coming of the factory, the astonishing conclusion is derived that the existence of the factory increases their attractiveness (their value, after all, has increased from $20,000 to $21,000). The residents are treated to cleaner and cooler air, and to the greater control of their interior environments, than they had before. With the direct method, one would ask: how much cleaner is the air than it was before? and how much cooler is the air? Then one would ask: what value do the residents put on the cooler, cleaner, and more uniform air? An intelligent purveyor of the direct method would recognize immediately that against the benefits of such better interior air, one must subtract the cost of the air conditioning (including capital and amortized operating costs) in order to arrive at net costs. Thus information must be gathered on the cost of the air conditioning, and on operating costs. Note that while the capital costs of the air conditioning would be fairly directly observable, the proper computation of operating costs is anything but simple. Suppose for simplicity that the only operating costs are charges for electrical power. Then operating costs refer to the increase in the electrical bill due to air conditioning. If electricity costs were constant, one could then compute the average amount of electrical power used by the air conditioners and multiply by the rate, to arrive, at least, at the private increase in operating costs. However, since electrical power is a "decreasing cost industry", utilities charge less for the marginal unit than for the average unit; thus the private operating costs depend upon whether the air conditioners tend to be used in periods of higher than average or lower than average usage. In fact, to go beyond private operating cost to social operating costs for electrical power, which is not a competitive industry, would require consideration of even more complex issues related to whether the air conditioners were used in periods of "peak load" utilization or not.

Nevertheless, reasonable approximations could surely be computed for the costs of having and running the air conditioners. In order to apply the direct method, one would not want to attribute those costs completely to the factory as external social costs for the reasons explained above. The benefits of the air conditioners would have to be quantified in commensurate terms and subtracted from total costs to arrive at the net costs of the adjustments. How should one value the cleaner, cooler, and more uniform air? "Direct" methods would probably include surveys of the residents, asking them "How much is it worth to you to have clean air rather than being forced to smell the obnoxious factory fumes?" Such surveys could also be used to attempt to find out how people "trade off" various dimensions of an externality, such as the frequency of the fumes versus their intensity. Surveys of that nature, in which people are asked to rank conjectural situations and to place "values" on the existence of conjectured changes, are often the basis for direct evaluations. See, for example, various studies of noise problems related to airports done by Bolt, Barenek, and Newman [1,2].

Unfortunately, such surveys are notoriously unreliable predictors of how people will react when placed in the actual situation conjectured. That conclusion is particularly well supported by the chronic difficulties of marketing specialists in attempting to forecast demand for a new product by asking people questions such as "Would you buy the following product described as .... at a price of $X?" Compared to the conjectured response which people are asked to make in the type of survey in which situations are ranked (e.g., "would you prefer to experience one very loud plane a day or five fairly loud planes a day?"), the marketing type questions are concrete. If marketing analysts find that extrapolating the proportions of people who say they would buy an item is a very unreliable method of forecasting demand, it seems plausible to suggest that people's actual reactions to situations are likely to be very different from their offhand responses to a survey questionnaire would suggest.

It is also important to recognize that there may be substantial incentives for people to exaggerate their welfare loss or to otherwise disguise their true feelings, depending on how they suspect the survey results will be used. In Chapter II, this possibility was discussed in the context of the problem of determining a Pareto optimal level of the production of a public good. However, it obviously also arises in any case in which those surveyed may modify their answers where they expect the survey results to be used to affect policies which concern them.

The power of the indirect method is obviously that the subjective evaluation of how much the air conditioning is worth, and of how the improved interior air is weighed against the degraded exterior air, is implicitly reflected in the value of the houses. Furthermore, the decrease in the market value of the houses (before air conditioning is installed), reflects precisely how the residents--and potential residents--weigh all of the advantages and disadvantages of the no-factory/no-air-conditioning situation against the factory/air-conditioning situation.

The direct method can be applied in its simplest form--where the external costs of an activity are assumed to be reflected entirely in its direct physical effects--only by assuming that those affected make no adjustments to the external effects. If external social costs are computed by observing the situation resulting after adjustments are made, there will be a systematic tendency to underestimate the extent of the external costs by ignoring the opportunity cost of some resources and by ignoring the direct costs of adjustment. As the factory example demonstrates, however, the appropriate modification of the calculations in the presence of adjustments may be very difficult and may raise further problems of measurement and evaluation. Clearly the moral of the example applies generally; for example, similar problems arise if, in the face of a sanitary landfill, surrounding houses erect fences and plant extensive shrubbery in order to replace a view of the landfill. If the fences and shrubbery improve the value of the property over what it would be in the absence of the landfill, the analogous problem of allocating their costs arises.

It must be noted that ignoring the effect of adjustment will produce the opposite bias--a systematic overestimate of the external costs--if the direct method is applied in contemplation of the existence of an activity with external effects. Thus in the factory/air-conditioning example, a survey of the residents of the surrounding houses would produce the conclusion, if it were done perfectly, that the coming of the factory would result in a decrease in utility equivalent to $3,000. The fallacy there is obviously that the possibility of air conditioning is ignored. A more general adjustment which might easily be ignored is the possibility that some residents would move, to be replaced by residents who are less sensitive to the external effect. Suppose, again purely for purposes of illustration, that residents and potential residents of the area surrounding the factory are of two types: those for whom the disutility from the factory fumes is equivalent to $3,000 and those for whom the disutility is equivalent to $500. Then assuming there are large numbers in both groups, the efficient distribution of homeowners clearly involves the area surrounding the factory being inhabited entirely by those who are less sensitive to the fumes.

Before the factory is contemplated, the residents would represent a random selection of the two groups. An accurate survey would thus uncover some proportion of residents who would evaluate the conjectured factory as equivalent to a loss of $2,000. Given a competitive housing market, however, they would not actually experience a loss of $2,000 if the factory comes. Instead, they would experience a loss equal to moving and searching expenses--including an amount equivalent to the "wear and tear" involved in moving--and possibly some loss in consumer surplus due to unique qualities of their former house and neighborhood. The costs related to moving are often ignored or underestimated by the indirect method, as we discuss below. However, it is important to note that where residents choose to move as a result of the appearance of some activity with external effects, the sum of their losses attributable to moving necessarily is less than their evaluation of the disutility due to the external effect.

Even if the presence of external effects of some activity does not produce adjustments on the part of those affected, there are often severe problems of measurement at both stages of the direct approach. Among the most severe problems is the multidimensional nature of the external effect in many cases. Consider, for instance, an activity which generates substantial noise, at levels which produce a significant impact on the surrounding area. While an airport is the obvious example, noise is also a potentially significant external effect associated with sanitary landfilling. But noise is not a homogeneous quantity. It varies in power, as measured in decibels, but a decibel reading summarizes only the power of the noise at one instant of time. Furthermore, it does not reflect the particular shape of the noise wave form; that is to say, it does not reflect the frequency or other qualities of the noise, qualities that often have as much or more to do with the disutility caused by noise as the power. Even if one is dealing with a homogeneous noise source, in which each episode consists of noise generated at a given decibel level, for a given duration, and with a given quality, there remain the problems of comparing different combinations of time patterns. Is a particular noise which occurs once every five minutes twice as much "total noise" as the same noise occuring once every ten minutes? Are twenty episodes within a five minute period worse than the same twenty episodes strung out over an hour? If worse, how much worse? More generally, is a noise of a given quality produced at 140 decibels worse than two episodes of the same quality at 110 decibels? Are occasional noises of high power worse than a steady drone at lower power?

In certain dimensions, such as ear drum damage these questions involving rankings of different time patterns and of different qualities of noise may have objective, "scientific" answers. Furthermore, the case of ear damage illustrates one situation where the indirect method of evaluation may be quite inappropriate, since it depends crucially on the assumption that the people affected by the externality are aware of the damage they are incurring and understand the nature and extent of the damage. We discuss that limitation of the indirect method below. But if we restrict the discussion here to the damage produced by the noise in terms of discomfort and annoyance, it is clear that such questions as those listed above do not have objective answers, and are meaningful only in terms of the subjective response of the affected person.

The output of the first phase of the direct method of evaluating external social costs is a catalogue of the physical manifestations of the external effect, measured with objective scales. In a case in which the external effect is multidimensional, as in the case of noise, the only completely appropriate output of the first phase must necessarily be a complete description of all dimensions of the effect. This may be an infeasible, extremely expensive task. In fact, it is impossible in the case of noise if the requirement is interpreted strictly since one dimension of noise is its precise quality, which is definable only in terms of combinations of an infinity of different wave forms.

Obviously substantial compromises have to be made with the conceptually appropriate procedure, in which the physical effects are first catalogued and their social costs are then evaluated. In particular, indices and summary measures must be substituted for the complete list of all dimensions and time patterns. But the only proper criteria by which to rank and combine different noise patterns, for instance, are subjective. One is then left with the choice of inferring such criteria from surveys and introspection, or by deriving them implicitly from observations on how individuals react to the different combinations of physical effects. Where the weights which individuals assign to different dimensions are implicitly determined, as they are by the impact of such external effects on property values, it seems unwise to ignore that information.

The multidimensionality of the external effect creates problems not only of weighing the various dimensions, but also of monitoring the physical effects. This latter problem is particularly severe with respect to the problem of water pollution, in particular the potential for groundwater pollution at a landfill. In Chapter IV, the numerous possible components of leachate from a landfill were described. It was also noted that the potential for groundwater pollution through leaching depends in extremely complex ways on the geological and hydrological characteristics of the landfill bed, on the distribution of rainfall, on the nature of the solid waste in the landfill, and on many other factors such as the vegetation on top of a completed landfill and the uniformity of settling. Furthermore, not only does the leachate consist of many different components whose proportions may vary enormously, but its relative concentration in the groundwater and its pattern of dispersion will depend on the particular extent and configuration of the groundwater flows. Thus, neither the quantitative nor the qualitative nature of groundwater pollution can be generalized from one landfill site to another with reasonable accuracy. Similar considerations apply to groundwater pollution attributable to carbon dioxide production. Since an adequately designed sanitary landfill is supposed to produce no water pollution problems at all, and since this objective is alleged to be feasible in acceptable sites, these considerations are possibly relevant only to open dumps or to landfills which do not meet specifications. However, it was noted in Chapter IV that leachate production and carbon dioxide production appears to be extremely long lived, and the groundwater pollution from a landfill could conceivable appear many years after the completion of a landfill site.

In the case where the damages caused by a particular external effect depend crucially on specific characteristics of the landfill site and cannot be easily predicted, it becomes extremely difficult to accurately include external social costs in the relevant policy calculations. Of course, this problem is not specific to the direct method of calculation;

if the external effects are highly variable and difficult to predict, the method of measurement cannot compensate for inherent uncertainty. In this situation it does not follow that such external effects should be ignored, however. If there is truly no way to accurately predict the extent of the external effects which will be produced, it is still preferable to attribute average external social costs to each proposed project, where the population of cases on which the average is calculated should be chosen from examples as comparable as possible. The attribution of such an average will counteract a bias which is otherwise present.

The last difficulty with the direct method of evaluation which we shall consider is the crucial importance of measuring the marginal impact of the activity in question. The external social cost attributable to an activity relates to the change in the relevant variables. If an open dump contributes to air pollution, for instance, the external social cost attributable to the dump activity must be measured as the total social cost of air pollution with the dump munus the total social cost without the dump. The important consideration here is that the social cost at the margin may differ considerably from the average social cost of the effect, and using an average figure may be very misleading.

One case in which the crucial importance of measuring the marginal effect is particularly obvious is where the external effect relates to noise. If a landfill is placed in a secluded residential area which was previously tranquil and idyllic, for instance, even a moderate amount of noise at the landfill and a moderate amount of heavy traffic to the fill may be considered extremely damaging by the surrounding residents. This is particularly likely in that the residents may well be a self selected group who have paid a premium, in land price and in inconvenience, in order to enjoy quiet. Placing a landfill in an industrial area, however, may be practically unnoticed by those in the area; the average noise level may be increased very slightly and the surrounding buildings may be already soundproofed. Implicit in these remarks is a noise-level/damage relationship as pictured in Figure 5.1a, where the marginal damage due to a given increase in the noise level is very high when the level is low, but decreases as the noise level increases. In that case, using average damages

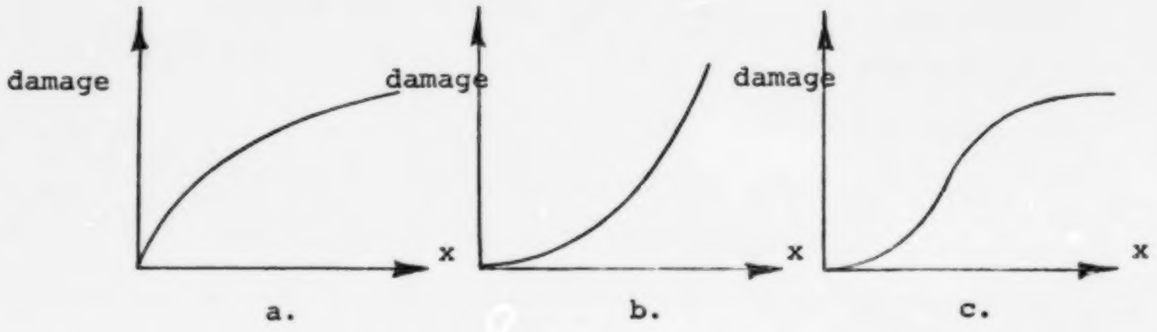

Figure 5.1 Three Possible Relationships between Damage (Social Cost) and the Level of Some Causal Variable x.

computed for a particular case as a proxy for marginal damages always results in overestimating the appropriate value. It is not inevitable that marginal damage should be decreasing, however. In some situations, a very small level of some variable (for instance, air pollution) might be unnoticeable and cause essentially no damage. As some "threshold" level is passed, however, the marginal damages become very great. Such a situation is depected in Figure 5.1b; in that case, using average damage as a proxy always produces an underestimate of the marginal damage. In Figure 5.1c, we show a mixed case where there is a threshold effect at low levels, but as the level increases a saturation effect becomes dominant. This latter case would seem to be a plausible representation of the damage/level relationship, although the relevant range for particular variables may be constrained to a certain section of such a curve. For such a relationship, the marginal damage resulting from a given increase in the variable becomes much greater than average damages as the threshold value is approached and becomes much smaller than average damage as the saturation level is approached. When computing the social cost attributable to some activity, the use of average damage as a proxy for marginal damage may result in a considerable bias.

The indirect method of evaluating the external social cost attributable to some activity finesses virtually all of the problems we have examined. Faced with the presence or with the prospect of an objectionable activity in the neighborhood, present and potential landowners are led to investigate the possibilities of reducing the "damage" by making adjustments such as air conditioning or fences or staying indoors more, and calculate the costs of such adjustments. The market value of surrounding property reflects the attractiveness of the property after an optimal set of adjustments is performed and the cost of those optimal adjustments. In their evaluation of how the external effects of the objectionable activity affect the attractiveness of the property, the different dimensions of the external effects are implicitly weighted. Furthermore, the weights which are implicit in the change in market value are not necessarily those of the residents living in the area when the offending activity is introduced (or first becomes foreseen), but the subjective weights of those to whom the property is valued highest in the face of the externality. The various dimensions of the external effects are thus combined with weights which implicitly reflect an economically efficient allocation of land, which is the appropriate criterion. Finally, since the indirect method evaluates the social cost of the external effects by comparing the surrounding property values with and without the presence of the objectionable activity, it automatically measures the marginal impact of the activity.

These assertions beg the question of how to estimate the change in property values as a result of the activity, obviously. Here one could take the direct approach of asking residents, or possibly local real estate experts, their opinions on the conjectural question of how property values would be affected if the objectionable activity were removed. It is the strong belief of most economists, however, that in such a situation the guesses of residents, even of real estate specialists, are likely to be crude and unreliable. Furthermore, as discussed in Chapter II, there may be strong incentives for people to misrespresent their true feelings. The economist's alternative approach is to construct an econometric model of property values in the area, using economic theory as a guide to the general design and specification of the model and statistics on property values and characteristics to calibrate the parameters of the model. Such an approach, if reasonably successful, implicitly measures the social costs of of the externalities in terms of what people do rather than in terms of what they say.

Obviously the results of the indirect method can only be as good as the underlying model of the determination of property values. Various attempts to construct and estimate such models were surveyed in Chapter III. Many of these studies are based on models which appear to include significant methodological errors. The specification of the model, and the estimation method used, are crucial to the validity of the final results. In constructing the econometric model which is estimated in Chapter VI, considerable effort was expended in attempting to specify a model which is based on a consistent theoretical analysis of the determinants of property values and which avoids apparent errors of previous studies. Nevertheless, it must be acknowledged that the success of such a model is severely limited by data availability. This is particularly true where the effects which are being estimated represent the impact on property values of secondary effects, such as the impact of a view or the impact of moderate road noise. Since there are a limited number of houses within an area which can be considered to share the same general location characteristics, the data limitation is inherent in the problem. This has to be considered an important disadvantage of the indirect method, although its significance depends upon the purpose of the study. If the objective is to estimate the effect of a nearby landfill rather precisely, say within $100, it is unrealistic to feel confident that an econometric model, calibrated with a modest number of observations, can provide such precision. This would require not only that the specification of other determinants of house value--such as square footage, number of rooms, size and shape of lot, et cetera--be virtually "perfect", but that one also have a large (say 1000) number of observations on which to estimate the model. The basic reason that generous data is probably necessary is that the attributes which make houses more attractive, such as size, number of bathrooms, quality of kitchen appliances and built-in fireplaces, quality of construction, location, lot size, and so forth, tend to be highly intercorrelated. Expensive houses tend to have more of all the things which make houses more attractive, and cheaper houses tend to have fewer and/or less of them. This makes it very difficult to statistically separate the effects of these different attributes. While it may not be necessary to infer precisely how these other attributes, which are not the effects that are of interest, affect the value of the house, the less accurate those inferences are, the more uncertain will be inferences about the effects of interest, such as the impact of increased road noise. It is not necessary, however, to worry independently about these effects on the reliability of the estimated effects that are of interest; the method of multiple regression analysis produces statistics useful in judging reliability which implicitly reflect the uncertainty in all of the other parameter estimates of the model.

It is also important to recognize that changes in property values ignore certain costs borne by those owning the surrounding property which are related to the possible uniqueness of the house or the property from the owner's point of view. The market value of a house does not represent what it is worth to its present owner, but to the potential buyer whose reservation price (the lowest price at which he is willing to buy it) is highest. In many cases, the value of the house to potential buyers becomes higher than its value to the owner. In that case, it becomes profitable for the owner to sell and move elsewhere, if the differential is large enough to compensate for the costs and headaches of moving and searching. In most cases, however, the value of a house to its owner is greater than its market value. This may be due either to unique aspects of the house and lot which the owner happens to value more highly than any potential buyer, but it is more usually due to the fact that the owner has modified and decorated the house to his own specific tastes. It may also be due to personal relationships with neighbors or other characteristics of the neighborhood which are valued by the owner.

It is thus often the case that an owner has positive consumer surplus in the house that he occupies, particularly if he has occupied the house for some time. In Chapter II the difficulties of unambiguously defining the notion of consumer surplus is analyzed, but its existence is not in doubt. When an objectionable activity with external effects appears in a neighborhood, it may affect not just the market value of the surrounding property but also wipe out consumer surplus. In particular, those who are led to move by the appearance of the activity do not receive compensation for their loss of consumer surplus, or even for their moving and searching costs. For those who choose to stay, their consumer surplus may be reduced more than the reduction in market value, so that the change in market value underestimates the cost to the owner. However, it is also possible, in the case where the resident chooses not to move, that consumer surplus increases in the face of the fall in market value, so that the decrease in market value overestimates the social cost. It must be emphasized that the consumer surplus referred to here relates to the unique qualities of the particular house, and not to houses of that general type or in that general area. While it would be preferable to be able to refine one's evaluations of social cost to take into account changes in that consumer surplus, such measurement is virtually impossible. The only source for such measurement would be to question the owner, who would have strong incentives to exaggerate his loss in welfare.

The most significant limitation of the indirect method, however, is that it can be justified in terms of standard economic theory only under the assumption of perfect knowledge. This assumption requires all buyers and sellers to be completely aware not only of the prices of all goods offered for sale, but also of the complete set of attributes of each individual product. In particular, the presumed connection between the market value of a house and the preferences of its potential owners for the different dimensions of "housing services" rests directly on the assumption that all potential buyers fully and completely appreciate all the "qualities" of each house.

If the housing market were truly characterized by perfect information, new owners would never be surprised, either by unforeseen defects or unforeseen virtues in a house. There would be no need for building codes, except for paternalistic motives. Obviously, such is not the case. Nevertheless, it is in the interests of prospective purchasers to carefully inspect a new house, and building codes greatly reduce uncertainty. Furthermore, it is rational for a potential buyer to expect a certain number of unforeseen problems to reveal themselves after he occupies the house, and to correspondingly "discount" his expected satisfaction level. Thus, even the admission of imperfect information about house attributes by potential buyers does not imply that there is a systematic bias in market values, although it does suggest that observed market values are not perfect indicators of what market values would be if information were perfect.

These considerations arise because potential buyers do not fully comprehend exactly how satisfied they would feel if they occupied the house. The perfect knowledge assumption implies that they do, and is obviously not strictly met in the real housing market. Nevertheless, this inaccuracy in the competitive model does not seem crucial. The more bothersome question is whether the satisfaction of of owners who occupy a house, even over a long period, should be uncritically used as a criterion of their own welfare.

The primary objection to that presumption--namely, that a person's satisfaction with his house should be the criterion of how much his particular house contributes to his welfare--is the situation where an individual may be unaware of some of the effects of his environment on his physical or mental health, particularly long term cumulative effects. Consider a house near an airport, for instance. The airport noise will be considered an irritation by most people, and their discomfort will be reflected in the market value of surrounding houses. But the airport noise may also damage their hearing ability, at a rate which is so slow as to be virtually unnoticeable but cumulatively still significant.

If people are unaware of the cumulative, permanent component of the damage, the market values of surrounding houses will reflect only the short run "nuisance" effect, but not the permanent component of the damage. Obviously, the reduction in market value may dramatically understate the external social cost of the external effect in such a case.

Such a bias is even more obvious where the homeowner is completely unaware of the external effect, as in the case where the water supply contains asbestos particles which are unnoticeable but harmful. Indeed, the discovery rate of toxic effects attributable to pollutants or chemical additives which were previously considered harmless appears to be accelerating. The evaluation of social costs in such cases by the indirect method is obviously nonsense where the homeowners are unaware of the hazard. In that situation, the direct method is the only alternative. Unfortunately, application of the direct method depends upon statistics which allow one to predict the incidence and severity of the relevant health problems on the basis of contamination rates. Since such data is often unavailable, the unsatisfactory procedure of basing policy on the most pessimistic assumption conceivable appears to prevail.

The second difficulty in applying the direct method in this case concerns the problem of evaluating the welfare loss resulting from the higher incidence of specific health problems or even death. The approach economists adopt here is not different in concept from evaluation problems in general, although complications related to uncertainty and people's attitudes toward risk arise. We will not attempt to summarize the extensive literature on the appropriate methods of doing benefit-cost analysis in the health area. In general, economists reject the agnostic view, as reflected in the statement that "it is absurd to believe that a dollar value can be put on human life", which is not a basis for policy decisions but for policy non-decisions. Rather, economists note that people implicitly trade off risks of death or disease against other goods continually, and that these decisions implicitly determine the "disutility" of death or ill health. Of course, inferences about such dimensions of people's preferences are different.

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CHAPTER VI

AN EMPIRICAL STUDY OF THE IMPACT OF SANITARY LANDFILLS ON RESIDENTIAL PROPERTY VALUES

A. INTRODUCTION

In this chapter we present the empirical results based on an analysis of the impact on property values of the presence of sanitary landfills in and near residential areas. Four sanitary landfills in the Los Angeles area were chosen for the study and detailed information was obtained about single family dwellings near these landfills which were sold during the last five years. The data for the study came from two sources; the Los Angeles County Assessor's Office and SREA Market Data Center Incorporated. Only those residential properties found in both the lists were included in the study, because much of the information available from one source was not available from the other and vice versa. For the selected residences, the data from both the sources were combined and used in the analysis.

Section B of this chapter describes the solid waste disposal practices in Los Angeles County. Section C discusses the determinants of residential property values, describes the variables used, and discusses the expected nature of their effect on property values. The actual empirical results are presented in Section D, and a summary of the conclusions is given in Section E.

B. LOS ANGELES COUNTY SOLID WASTE DISPOSAL PRACTICES

Solid waste disposal facilities in Los Angeles County are currently provided by three distinct entities: the County Sanitation Districts, municipalities, and private operators. Any discussion of solid waste management practices, therefore, must be segregated into these same three catagories.

At the present time three cities (Los Angeles, Burbank, and Whittier) operate their own landfill sites. The latter two cities have only one site each and handle a comparatively small volume of solid waste (see Table 6.1). In addition, each of these sites is closed to the public; only city operated collection vehicles are permitted to use their respective landfill site. The City of Los Angeles (referred to as the City from this point on) operates two landfill sites with a combined volume of over one million tons per year (see Table 6.1). These two sites receive approximately two-thirds of the refuse collected by City forces, with the remaining one-third disposed of at sites operated by the County Sanitation Districts [2].

During the past few decades the City has shown a flexible attitude toward solid waste disposal techniques. Prior to 1955 the householder segregated his refuse, with garbage collected separately by both City forces and private collectors and disposed of under contract to hog feeders. Other wastes, including ashes and noncombustibles, were collected and dumped in outlying areas. Combustible rubbish was burned on the homeowner's property or hauled away by private collectors [2].

In 1955, a pilot project was started in the Harbor area for the collection of combustible rubbish as a third separate service by the City. This change was motivated by the demand for cleaner air and the elimination of the backyard incinerator, officially legislated in 1957. In the early years of the combustible rubbish collection program, the City attempted to maintain a salvage and reclamation service, but it soon became apparent that this procedure was simply increasing costs. By 1961 garbage disposal units had reduced residential food wastes to a very small percentage of the volume during the 1950's. Furthermore, as a result of advances in the container industry, the supply of separately collected glass and metals had declined to less than 30% of its peak value by 1964. At this time a combined collection program was instituted with all household refuse to be used as fill material for park and land reclamation, a practice which has continued until the present [2].

At the present time there are twenty-five landfill sites being operated in Los Angeles County: six by the County Sanitation Districts, four by municipalities, and fifteen by private operators. There is no mode of solid waste disposal other than that of the sanitary landfill currently in use in the County [3]. Table 6.1 provides an ennumeration of these sites together with information on the acreage of and volume handled at each site. Although some of the site names include the word "dump", there are no open dumps operated in Los Angeles County; all solid waste has been disposed of by the sanitary landfill method since 1964 [3].

The current service given by the Bureau of Sanitation in the City of Los Angeles is the combined collection of all household and yard wastes on a one time per week basis, and the collection of commercial garbage at a minimum of twice a week and more frequently as required by the customer. More than 1,200,000 tons of refuse are collected and disposed of each year. Of this total, the collection of commercial garbage from such establishments as restaurants and hotels accounts for only 6,000 tons and the collection of animal carcasses another 1,500 tons. The great preponderance of refuse collected, therefore, is that which comes from the City's residential units. For locations producing large quantities of refuse, such as high density apartment complexes, the standard weekly collection service is increased to three or five times per week. This service is supported from general tax funds without special fees being levied against the homeowner [3].

Commercial garbage is collected from restaurants, hotels, hospitals, and other establishments on a basis of payment for each collection, with a minimum of two stops required per week. The collection of animal carcasses is provided without charge for both animal hospitals and the homeowner [3].

The City's Bureau of Sanitation owns and operates a fleet of approximately 650 vehicles, including: 500 packer-type refuse collection vehicles, as well as earth movers, tractors, utility collection vehicles, and smaller service units. Refuse deposited in the rear loading compartment of the packer vehicle is compacted to about one-half its original volume by a hydraulically activated packer blade. Trucks with a capacity of 25 cubic yards have been found to be more suitable for use in the residential collection operation, while smaller units with a 16 cubic yard capacity are used in areas where more maneuverability is required [3].

The Los Angeles County Sanitation Districts operate six landfill sites: Palos Verdes Landfill, Spadra Landfill, Mission Canyon Landfill, Calabasas Landfill, Scholl Canyon Landfill, and the Puente Hills Landfill. All these sites are open to private citizens, rubbish haulers, gardeners, municipalities, school districts, County agencies, and industry. These groups are permitted to dispose of waste material including: combustible and noncombustible rubbish, garbage, paper, grass, tree and yard trimmings, lumber, tires, cans, bottles etc., but excluding separate loads of garbage. The charge for disposing of each of these materials depends on the site involved; Figures 6.2 through 6.7 provide a detailed listing of these charges at each of the County landfills.

There are now a total of twenty-seven County Sanitation Districts, the first established in 1923. They are governed by a Board of Directors made up of the mayors and county supervisors whose jurisdictional areas are involved. The Districts stretch from the eastern border of the City of Los Angeles to Pomona and from Long Beach to Lancaster and include a total of seventy-one cities. By combining under a single administration it is possible to attack problems on a regional basis. Prior to 1957 the

Districts were concerned strictly with sewage treatment, but with the legislated demise of the backyard incinerator they were thrust into the refuse problem. Preparations had been underway since 1950 to provide for the transfer and disposal of refuse, though the house to house collection remained in the hands of local authorities [7].

At the present time the Board of Directors feels that sanitary landfills are the most economical and nuisance free method for the disposal of solid waste. Depleted gravel pits and unused mountain canyons provide the County with many acceptable sites for land reclamation under this method of disposal. During the filling operation, the refuse is compacted and covered with earth each day in order to maintain a clean land mass. Properly managed landfill sites have become aesthetically acceptable land which has been used to create parks, playgrounds, golf courses, and other community improvement projects. Other refuse disposal methods, such as composting, incineration, and ocean disposal have been considered and evaluated; however, none have been found to be as practical as the sanitary landfill method for use at this time. Sites chosen by the City and County are selected with great care. Among the important factors considered in such selection are the feasibility of land acquisition at a reasonable cost, the suitability of the reclaimed land for subsequent beneficial use, and the proximity of the site to the collection area to be served. The reader may refer to Figure 6.1 to see the distribution of all landfill sites throughout Los Angeles County [7].

There are fifteen privately operated landfill sites in Los Angeles County which handle approximately 38% of the total solid waste volume. The majority of these sites are abandoned gravel pits which, being nothing but huge excavations, have little value in other uses. The private operators run the landfill until the pit is filled and then attempt to sell the site to the State or County as park or recreation land. As one would expect of abandoned gravel pits, these sites are mostly located in industrial areas, near operating gravel pits or other types of heavy industry. Although the private sites will accept business from any source (private, municipal, and industrial) the latter source provides the greatest volume due to its proximity to these sites.

For the purposes of this study four landfills have been chosen: Palos Verdes, Calabasas, Sheldon-Arleta and Tujunga. Descriptions of these four sanitary fills are given in Section D. These fills were chosen because of their proximity to residential areas. Several sites were rejected as being unsuitable for the purposes of this study. For instance, the Mission Canyon landfill is rimmed by mountains, and there are no homes within two miles of the site. However, a new tract has just been started one-half mile away and it may be of interest to study their property values a few years from now.

The North Valley site is also not suitable because it is over five miles away from residential areas. The Bradley pit is surrounded by industry and freeway and the closest home is over one-half mile away. None of the homes have a direct view of the landfill. The Burbank dump was also rejected because it is in the mountains, is completely hidden from view and is over a mile from the nearest homes. Both Owl Park and Alpha Investment are in the same highly industrialized area. They are both gravel pits used by neighboring firms to dispose of heavy materials. There are some homes about a mile away but they have no view of the fill. Furthermore, the gravel pits themselves are much more offensive because they cause dust and noise and have machinery which stand over 100 feet high.

Table 6.1 OPERATING LANDFILL SITES IN LOS ANGELES COUNTY

Site (Acreage)	Fill Rate (Tons/Year)		
	Sanitation Districts	Municipal	Private
1) Palos Verdes Landfill (220)*	1,600,000		
2) Spadra Landfill (185)	180,000		
3) Mission Canyon Landfill (485)	1,400,000		
4) Scholl Canyon Landfill (345)	500,000		
5) Calabasas Landfill (380)	260,000		
6) Puente Hills Landfill (265)	940,000		
7) Sheldon-Arleta Pit (60)		510,000	
8) Toyon Canyon Landfill (150)		730,000	
9) Burbank City Landfill (150)		120,000	
10) City of Whittier Landfill (32)		36,000	
11) North Valley Refuse Center (300)			360,000
12) Bradley Avenue			600,000
13) Hewitt Pit (64)			280,000
14) Tujunga Pit (66)			370,000
15) Azusa Rock and Sand (40)			250,000
16) Owl Park (60)			84,000
17) Canyon Park Development (15)			95,000
18) B.K. Co. (45)			560,000
19) Operating Industries (182)			900,000

*The location of a landfill is identified in Figure 6.1 by the corresponding number in the table.

Table 6.1 (continued). OPERATING LANDFILL SITES IN LOS ANGELES COUNTY

Site (Acreage)	Fill Rate (Tons/Year)		
	Sanitation Districts	Municipal	Private
20) Norwalk Dump (18)			14,000
21) Kobra Landfill (15)			41,000
22) Ascon (60)			300,000
23) Lancaster Dump (24)			18,000
24) Antelope Valley Landfill (40)			20,000
25) Chiquita Canyon Landfill (97)			28,000
Subtotals	4,880,000	1,396,000	3,910,000
Total		10,186,000	

Source: Existing Landfills in Metropolitan Los Angeles County, County Sanitation Districts of Los Angeles County, 1970.

Note: The figures in parentheses represent the areas, in acres, of the corresponding landfill.

Figure 6.1 EXISTING LANDFILLS IN METROPOLITAN LOS ANGELES COUNTY.

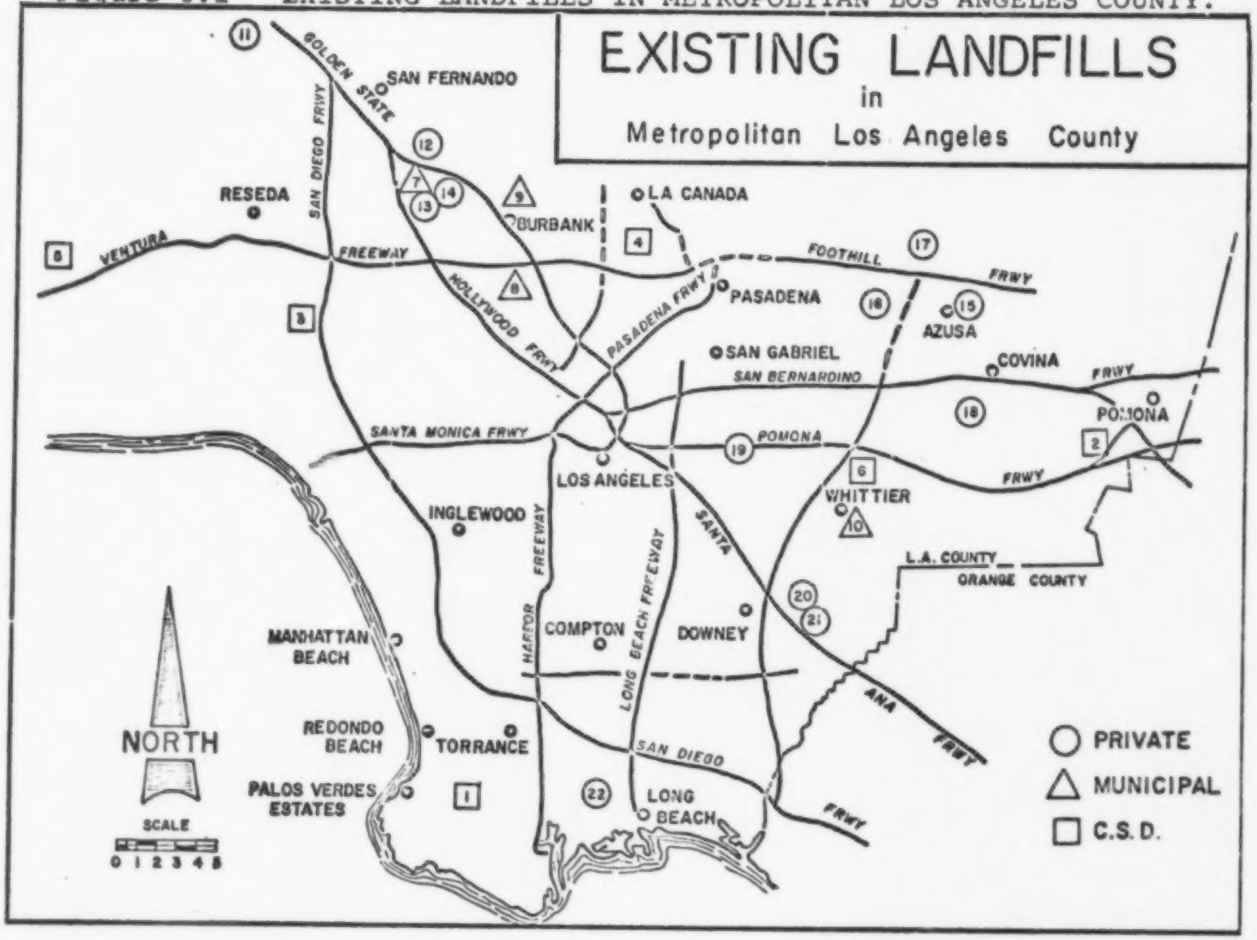
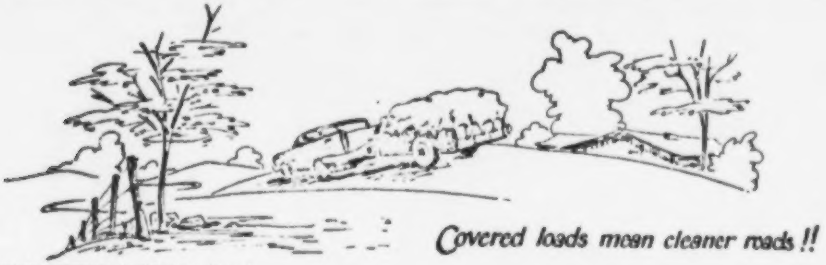
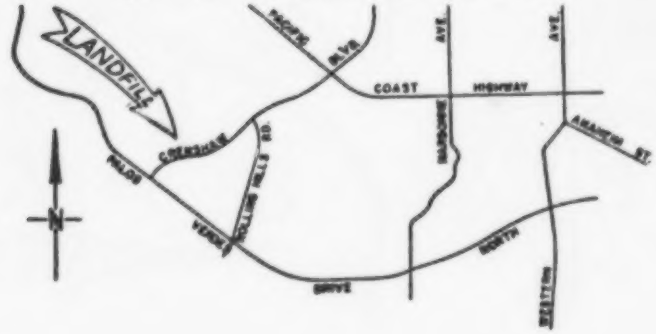

EXISTING LANDFILLS
in
Metropolitan Los Angeles County
11
GOLDEN STATE
SAN FERNANDO
SAN DIEGO FRWY
12
7
13
14
9
BURBANK
RESEDA
LA CANADA
4
FOOTHILL
17
FRWY
5
VENTURA
FREEWAY
HOLLYWOOD FRWY
8
3
PASADENA FRWY
PASADENA
16
15
AZUSA
SAN GABRIEL
SAN BERNARDINO
COVINA
FRWY
POMONA
18
SANTA MONICA FRWY
19
POMONA
2
FRWY
LOS ANGELES
6
WHITTIER
10
INGLEWOOD
HARBOR FREEWAY
LONG BEACH FREEWAY
SANTA
L.A. COUNTY
ORANGE COUNTY
20
21
COMPTON
DOWNEY
MANHATTAN BEACH
ANA
FRWY
REDONDO BEACH
TORRANCE
SAN DIEGO
NORTH
PALOS VERDES ESTATES
1
22
LONG BEACH
FRWY
SCALE
0 1 2 3 4 5
PRIVATE
MUNICIPAL
C.S.D.

Figure 6.2 PALOS VERDES, LANDFILL NO. 1


Covered loads mean cleaner roads !!

PALOS VERDES LANDFILL NO. 1
(Operated by County Sanitation Districts)

WHERE	26301 So. Crenshaw Blvd., Rolling Hills, Calif. 772-2631, 377-3514	
WHO	Open to all private citizens, rubbish haulers, gardeners, municipalities, school districts, county agencies, industries, etc.	
WHAT	Solid and liquid wastes, combustible and noncombustible rubbish, wrapped household garbage, paper, grass, tree and yard trimmings, lumber, tires, cans, bottles, etc., but excluding separate loads of garbage.	
HOW MUCH	Refuse	$2.00 per ton
	Solid inert material (rock, dirt, etc.). . . .	1.25 per ton
	Hard-to-handle, bulky materials.	3.00 per ton
	Liquid wastes.	2.00 per ton
	Minimum charge	2.00 per load
	Load pull-off.	2.00 per pull
	Tank washout	2.00 per wash
WHEN	8:00 A.M. to 5:00 P.M. daily excepting Sundays and Holidays	
CREDIT	See weighmaster for application forms, or contact Sanitation District office, 2020 Beverly Blvd., Los Angeles, Calif. 90057, 484-1370. Checks cannot be accepted at the landfill.	
SANITATION	Cover loads in accordance with all city, county and state regulations.	
LOCATION	See map shown below. Dump only at spots designated by landfill personnel. Observe speed regulations on site.	


LANDFILL
PACIFIC
BLVD.
COAST
HIGHWAY
AVE.
AVE.
NARBONNE
ANAHEIM ST.
CRENSHAW
ROLLING HILLS RD.
PALOS
VERDES
DRIVE
NORTH
WESTERN
N

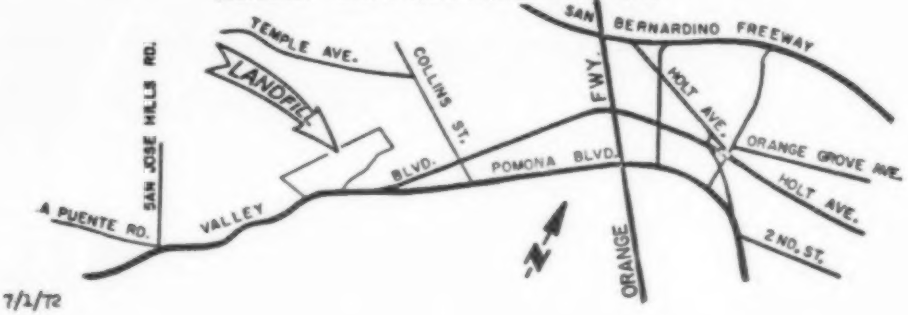
4/1/71

Figure 6.3 SPADRA, LANDFILL NO. 2

Covered loads mean cleaner roads !!

SPADRA LANDFILL NO. 2
(operated by County Sanitation Districts)

WHERE	4125 West Valley Blvd., Walnut, California. (714) 595-2710	
WHO	Open to all private citizens, rubbish haulers, gardeners, municipalities, school districts, county agencies, industries, etc.	
WHAT	Waste material, including combustible and noncombustible rubbish, garbage, paper, grass, tree and yard trimmings, lumber, tires, cans, bottles, etc., but excluding separate loads of garbage.	
HOW MUCH	Refuse	$1.60 per ton
	Solid inert material (rock, dirt, etc.)	1.10 per ton
	Hard-to-handle, bulky materials	2.50 per ton
	Liquid wastes	1.60 per ton
	Minimum charge	2.00 per load
	Load pull-off	2.00 per pull
	Tank washout	2.00 per wash
WHEN	8:00 A.M. to 5:00 P.M. Monday Through Saturday. 12:00 Noon to 4:00 P.M. Sundays. Closed Holidays.	
CREDIT	See weighmaster for application forms, or contact Sanitation District office, 2020 Beverly Blvd., Los Angeles, Calif. 90057, 484-1370. Checks cannot be accepted at the landfill.	
SANITATION	Cover loads in accordance with all city, county and state regulations.	
LOCATION	See map shown below. Dump only at spots designated by landfill personnel. Observe speed regulations on site.	


SAN BERNARDINO FREEWAY
TEMPLE AVE.
COLLINS ST.
LANDFILL
SAN JOSE HILLS RD.
FWY.
HOLT AVE.
ORANGE GROVE AVE.
POMONA BLVD.
BLVD.
HOLT AVE.
A PUENTE RD.
VALLEY
N
ORANGE
2ND. ST.

7/1/72

Figure 6.4 MISSION CANYON-SEPULVEDA, LANDFILL NO. 3

Covered loads mean cleaner roads!!

MISSION CANYON-SEPULVEDA LANDFILL NO. 3
(Operated by County Sanitation Districts)

WHERE	2201 No. Sepulveda Blvd., West Los Angeles, Calif. 272-2942	
WHO	Open to all private citizens, rubbish haulers, gardeners, municipalities, school districts, county agencies, industries, etc.	
WHAT	Waste materials, including combustible and noncombustible rubbish, wrapped household garbage, paper, grass, tree and yard trimmings, lumber, tires, cans, bottles, etc., but excluding separate loads of garbage.	
HOW MUCH	Refuse	$1.60 per ton
	Solid inert material (rock, dirt, etc.). . . .	1.10 per ton
	Hard-to-handle, bulky materials.	2.50 per ton
	Minimum charge	2.00 per load
	Load pull-off	2.00 per pull
WHEN	8:00 A.M. to 5:00 P.M. daily excepting Sundays	
CREDIT	See weighmaster for application forms, or contact Sanitation District office, 2020 Beverly Blvd., Los Angeles, Calif. 90057, 484-1370. Checks cannot be accepted at the landfill.	
SANITATION	Cover loads in accordance with all city, county and state regulations.	
LOCATION	See map on reverse side. Dump only at spots designated by landfill personnel. Observe speed regulations on site.	

7/1/72

Figure 6.5 MAP OF MISSION CANYON LANDFILL

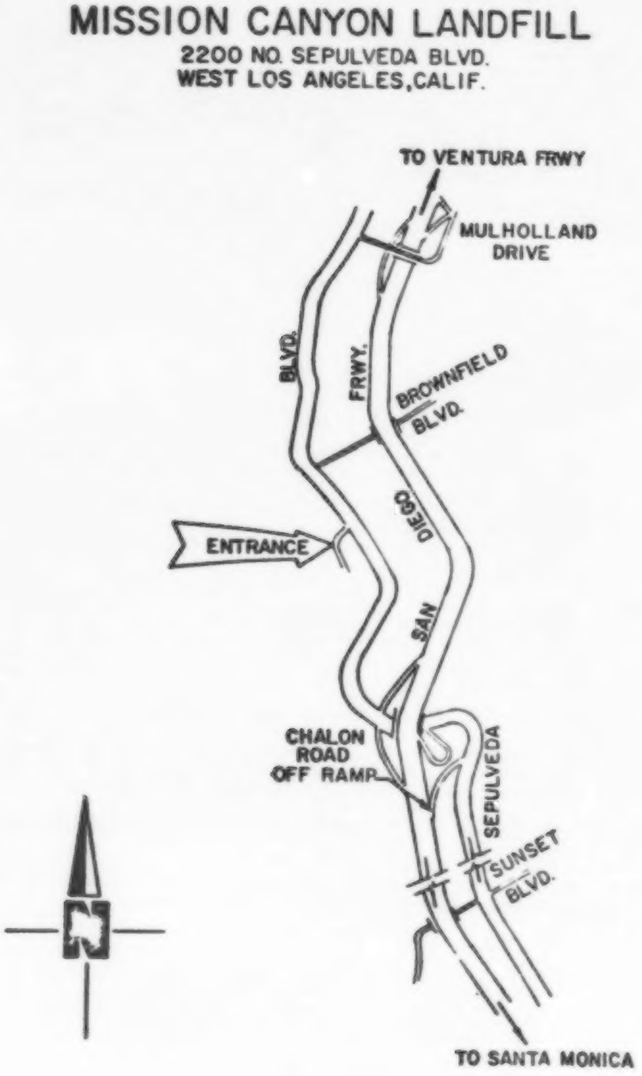

MISSION CANYON LANDFILL
2200 NO. SEPULVEDA BLVD.
WEST LOS ANGELES, CALIF.
TO VENTURA FRWY
MULHOLLAND DRIVE
BLVD.
FRWY.
BROWNFIELD BLVD.
ENTRANCE
DIEGO
SAN
CHALON ROAD OFF RAMP
SEPULVEDA
SUNSET BLVD.
TO SANTA MONICA
N

Figure 6.6 SCHOLL CANYON, LANDFILL NO. 4

Covered loads mean cleaner roads!!

SCHOLL CANYON LANDFILL NO. 4
(Operated by County Sanitation Districts)

WHERE	7546 No. Figueroa St., Los Angeles, Calif. 245-4315
WHO	Open to all private citizens, rubbish haulers, gardeners, municipalities, school districts, county agencies, industries, etc.
WHAT	Waste materials, including combustible and noncombustible rubbish, wrapped household garbage, paper, grass, tree and yard trimmings, lumber, tires, cans, bottles, etc., but excluding separate loads of garbage.
HOW MUCH	Refuse . . . . $1.60 per ton
	Solid inert material (rock, dirt, etc.). . . . 1.10 per ton
	Hard-to-handle, bulky materials. . . . . 2.85 per ton
	Minimum charge . . . . 2.00 per load
	Load pull-off . . . . 2.00 per pull
WHEN	8:00 A.M. to 5:00 P.M. daily excepting Sundays
CREDIT	See weighmaster for application forms, or contact Sanitation District office, 2020 Beverly Blvd., Los Angeles, Calif. 90057, 484-1370. Checks cannot be accepted at the landfill.
SANITATION	Cover all loads in accordance with all city, county and state regulations.
LOCATION	See map on reverse side. Dump only at spots designated by landfill personnel. Observe speed regulations on site.

7/1/72

Figure 6.7 MAP OF SCHOLL CANYON LANDFILL

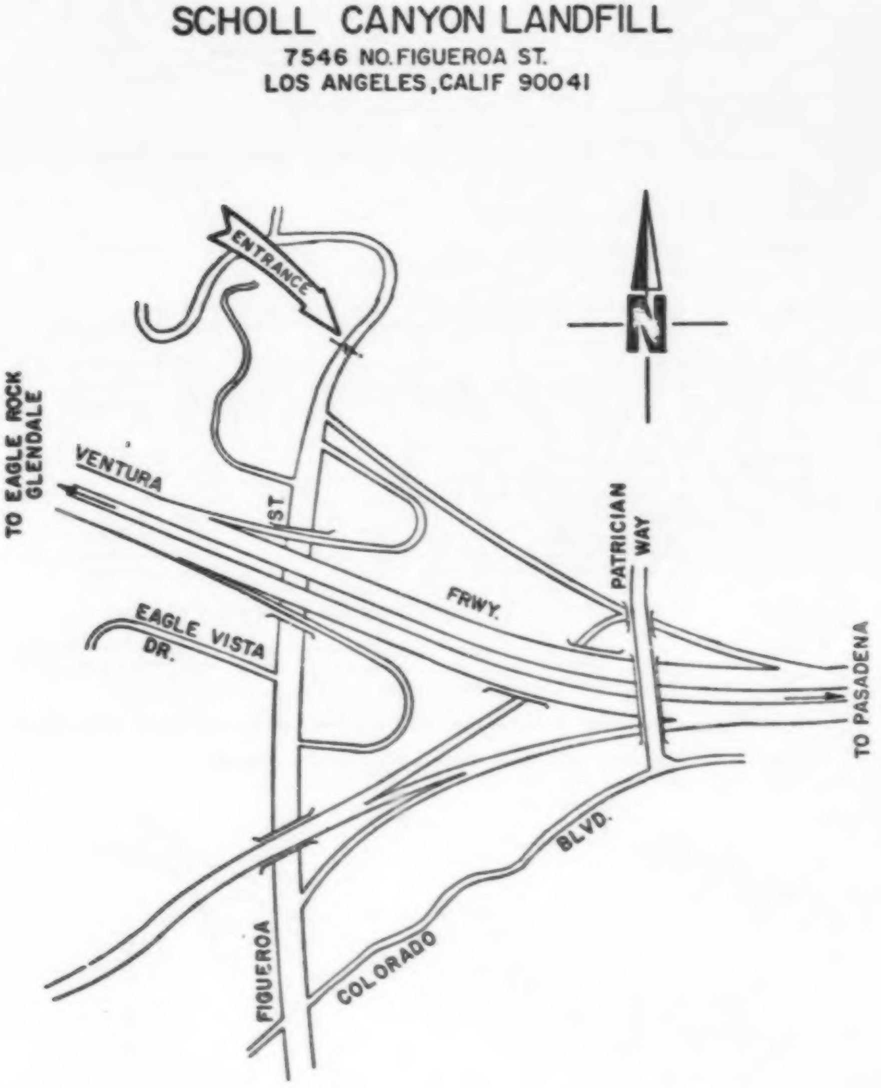

SCHOLL CANYON LANDFILL
7546 NO. FIGUEROA ST.
LOS ANGELES, CALIF 90041
ENTRANCE
N
TO EAGLE ROCK
GLENDALE
VENTURA
ST.
FRWY.
PATRICIAN
WAY
EAGLE VISTA
DR.
TO PASADENA
BLVD.
COLORADO
FIGUEROA

Figure 6.8 .CALABASAS, LANDFILL NO. 5

. *Covered loads mean cleaner roads!!*

CALABASAS LANDFILL NO. 5
(Operated by County Sanitation Districts)

WHERE 26919 West Ventura Freeway, Agoura, Calif. Phone - 889-1430
One Mile west of Las Virgenes Road.

WHO Open too all private citizens, rubbish haulers, gardeners, municipalities, school districts, county agencies, industries, etc.

WHAT Solid and liquid wastes, combustible and noncombustible rubbish, wrapped household garbage, paper, grass, tree and yard trimmings, lumber, tires, cans, bottles, etc., but excluding separate loads of garbage.

HOW MUCH

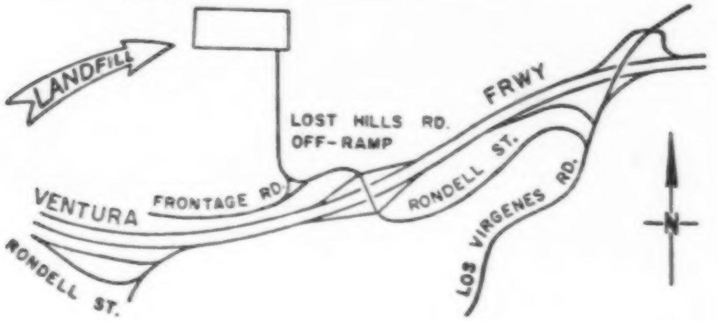
Refuse	$1.60 per ton
Solid inert material (rock, dirt, etc.). . . .	1.10 per ton
Hard-to-handle, bulky materials.	2.50 per ton
Liquid wastes.	1.60 per ton
Minimum charge	2.00 per load
Load pull-off.	2.00 per pull
Tank washout	2.00 per wash

WHEN 8:00 A.M. to 5:00 P.M. daily excepting Sundays and Holidays.

CREDIT See weighmaster for application forms, or contact Sanitation District office, 2020 Beverly Blvd., Los Angeles, Calif. 90057, 484-1370. Checks cannot be accepted at the landfill.

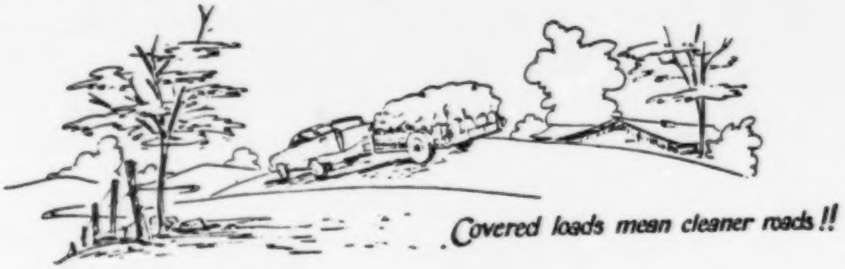
SANITATION Cover loads in accordance with all city, county and state regulations.

LOCATION Take Lost Hills Road turnoff from Ventura Freeway.
See map shown below.



7/1/72

Figure 6.9 PUENTE HILLS, LANDFILL NO. 6

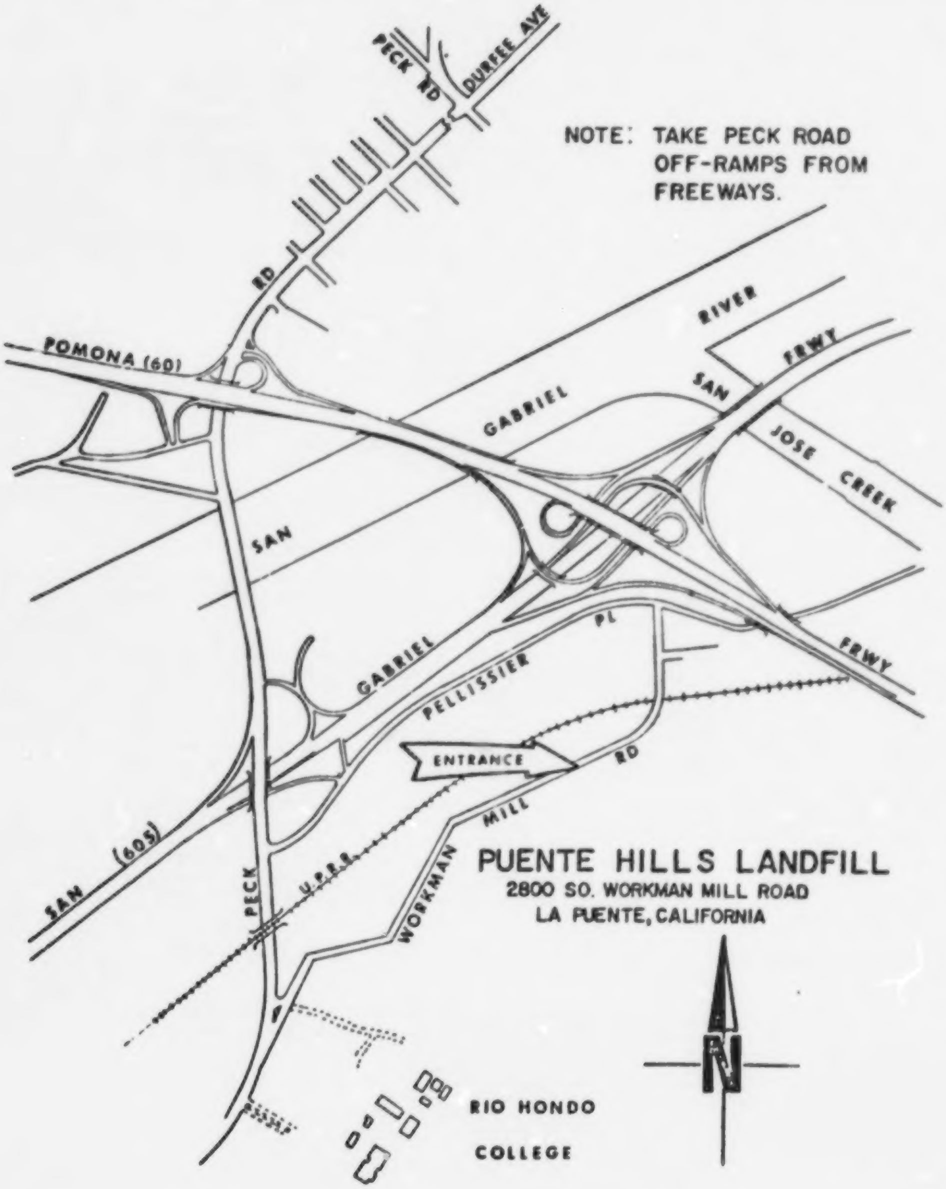

Covered loads mean cleaner roads!!

PUENTE HILLS LANDFILL NO. 6
(Operated by County Sanitation Districts)

WHERE	2800 So. Workman Mill Road, La Puente, Calif. Local: 699-5204. From Los Angeles: 723-9264.
WHO	Open to all private citizens, rubbish haulers, gardeners, municipalities, school districts, county agencies, industries, etc., but excluding separate loads of garbage.
WHAT	Waste material, including combustible and noncombustible rubbish, garbage, paper, grass, tree and yard trimmings, lumber, tires, cans, bottles, etc.
HOW MUCH	Refuse . . . . $1.60 per ton Solid inert material (rock, dirt, etc.). . . . 1.10 per ton Hard-to-handle, bulky materials. . . . . 2.50 per ton Liquid wastes. . . . . 1.60 per ton Minimum charge . . . . 2.00 per load Load pull-off. . . . . 2.00 per pull Tank washout . . . . 2.00 per wash
WHEN	6:00 A.M. to 5:00 P.M., Monday through Saturday. 8:00 A.M. to 4:00 P.M. Sunday.
CREDIT	See weighmaster on site for application forms, or contact Sanitation District office, 2020 Beverly Blvd., Los Angeles, Calif. 90057, 484-1370. Checks cannot be accepted at the landfill.
SANITATION	Cover loads in accordance with all city, county and state regulations.
LOCATION	See map on reverse side. Dump only at spots designated by landfill personnel. Observe speed regulations on site.

7/1/72

Figure 6.10 MAP OF PUENTE HILLS LANDFILL


PECK RD
DURFEE AVE
NOTE: TAKE PECK ROAD OFF-RAMPS FROM FREEWAYS.
RD
POMONA (60)
RIVER
SAN FRWY
GABRIEL
SAN
JOSE CREEK
SAN
GABRIEL
PL
PELLISSIER
FRWY
ENTRANCE
RD
MILL
WORKMAN
SAN (605)
PECK
U.P.R.R.
PUENTE HILLS LANDFILL
2800 SO. WORKMAN MILL ROAD
LA PUENTE, CALIFORNIA
N
RIO HONDO
COLLEGE

C. DETERMINANTS OF RESIDENTIAL PROPERTY VALUES

It is well recognized that the sale price or assessed value of a given property depends on a number of attributes of the property. Thus, the relationship between the price and characteristics of a house can be expressed in the form

$$P_i = f(x_{i1}, x_{i2}, \ldots, x_{ij}, \ldots, x_{in})$$

where P_i is the price and x_{ij} is the jth attribute of the ith residence. A similar relationship can be written down between the assessed value of a house and the attributes. The exact specification of the relationship will be discussed later. The number of individual characteristics of any property is unmanageably large. In practice, we are thus limited to measuring the most important attributes in each of several broad categories and modeling the effects of the unmeasured attributes as an error or disturbance term.

The characteristics of a property are basically of two types, (1) characteristics of the house and (2) characteristics of the neighborhood. The house characteristics can be further subdivided into two types, basic attributes and improvements. Neighborhood characteristics can take the form of amenities as well as disamenities. In this section, we describe the various attributes of a property for which information could be obtained. The nature of the expected relationship between price or assessed value and the characteristics of a residence are also discussed. The complete list of the variables and their definitions are given in Table 6.2.

As indicated above, property values are measured by two variables: the price at which it was last sold (PRICE) and the assessed value (ASSVAL). In this study, models in which each of these measures is used as the dependent variable are estimated. Some of the issues involved in specifying how the house and neighborhood characteristics influence property values can be made evident by considering how the amount of living space (AREA) and land area (LOTSIZ) might influence property values. Both PRICE and ASSVAL include the value of both land and house. Consequently, we would expect that the larger the size of the lot (measured in square feet), the higher will be the value of the residential property. We can also expect that the living area (measured in square feet) would exhibit a positive relationship to residential value. *Ceteris paribus*, a house with a larger living area is likely to be more valuable. However, to the extent that in our sample larger houses are found on larger lots, it

Table 6.2 LIST OF VARIABLES AND THEIR DEFINITIONS

AFLOOR	FLOORS · AREA
AGERDD	1 - exp[R(AGE - DD)] where AGE is the age of the house in years, DD is the useful lifetime, and R is the discount rate. Alternative values for R = .02, .04, .06, for DD = 50, 100, 150 (DD = 100 and 150 are denoted by 10 and 15). Note that a newer house means a higher value for AGERDD.
AIRCON	1 if no air conditioning 2 if wall or evaporative cooler 3 if central air conditioning
APPL	1 if no range/oven or dishwasher 2 with one of them 3 with both of them
AREA	Living area in square feet
ASSVAL	Assessed value in dollars (including that of land)
AV/LOT	Assessed value per square foot of lot size
BDROOM	Number of bedrooms
BTHRUM	Number of bathrooms
CLFRNT	CULDSC · FRONT
CLLFRN	CULDSC · log(FRONT)
CONDN	Condition of maintenance: 1 = poor 2 = fair 3 = average 4 = good 5 = excellent
CONDO	1 for condominium, 0 otherwise

Table 6.2 (continued). LIST OF VARIABLES AND THEIR DEFINITIONS

CONST	Constant term
CORNLT	1 for a corner lot, 0 otherwise
CRFRNT	CORNLT · FRONT
CRLFRN	CORNLT · log(FRONT)
CULDSC	1 for cul-de-sac, 0 otherwise
DFILL	Distance to sanitary landfill (all distances are in hundreds of feet)
DFRWY	Distance to nearest point of freeway
DGOLF	Distance to golf course, if any
DJUNK	Distance to any disamenities
DOWNP	Down payment as a fraction of sale price
DPARK	Distance to nearest park
DRAMP	Distance to freeway ramp
DSHOP	Distance to nearest shopping center
DTRUCK	Distance to dump truck route
DUMPi	1 for dump # i (i = 1,..., 4)
FIREPL	1 + number of fireplaces
FLOORS	1 for more than one floor
FRONT	Front footage of lot measured in feet
GARAGE	1 + number of car spaces in garage
LARFLR	log(AREA) · FLOORS
LEASE	1 for lease
LLOTPL	log(LOTSIZ) · log(POOL)

Table 6.2 (continued). LIST OF VARIABLES AND THEIR DEFINITIONS

LOTSIZ	Size of lot in square feet
LTSZPL	LOTSIZ · POOL

(Other variables beginning with L or LG denote the logarithm of what follows; three examples are given below)

LAG415	log(AGE415) (with R = .04 and DD = 150)
LAV/LT	log(AV/LOT)
LGAPPL	log(APPL)
MAINST	1 if house is on main street
ODDLOT	$\lvert \hat{P}/\sqrt{S} - \bar{R} \rvert$ where $\hat{P}$ = estimated perimeter, S = area of lot $\bar{R}$ = average $\hat{P}/\sqrt{S}$ for sample houses near a fill
OTHRUM	Number of other rooms excluding bedrooms, bathrooms, and kitchen
POOL	1 if no pool 2 if non-heated pool 3 if heated pool
PRICE	Sale price in hundreds of dollars
PR/LOT	Price per square foot of lot size
QUALTY	Quality of construction: 1 = poor 2 = average 3 = good 4 = excellent or luxury
REMODL	1 if no remodelling 2 if kitchen, bathroom, or both remodelled 3 if completely remodelled
SALDAT	Date of sale in fractional years (e.g., March, 1970 = 70.25)
VIEWFL	1 if fill is visible from the residence

Table 6.2 (continued). LIST OF VARIABLES AND THEIR DEFINITIONS

VIEWLT	1 if lot has good view
WIND	Number of degrees away from prevailing downwind from the fill
YARDSZ	LOTSIZ - AREA

may be difficult to distinguish the effects of these two variables. In the case of both area and lot size, it is reasonable to expect that the additional units of each variable would add to the property value at diminishing rate. Thus, the extra value of an additional 100 square feet of area or lot size is likely to be more for a small house than for a large house. Furthermore, the value of extra square feet of living space may depend on the lot size and vice versa.

There are at least two alternative ways in which the hypothesis implicit in the above statement may be tested. First, consider the following specification:

$$\text{PRICE} = \alpha_o + \alpha_1\text{AREA} + \alpha_2(\text{AREA})^2 + \alpha_3\text{LOTSIZ} + \alpha_4(\text{LOTSIZ})^2 + \alpha_5\text{AREA}\cdot\text{LOTSIZ} + Z \qquad (6.1)$$

where Z represents the effects of other characteristics of a house which are held constant for the moment, and α_i's are the unknown coefficients to be estimated from the data. Partially differentiating this with respect to AREA, we have

$$\frac{\partial\text{PRICE}}{\partial\text{AREA}} = \alpha_1 + 2\alpha_2\text{AREA} + \alpha_5\text{LOTSIZ} \qquad (6.2)$$

The above relationship specifies that the addition in the price due to a unit addition in the living area depends on the living area itself and the size of the lot. A similar statement can be made with respect to the effect of LOTSIZ on PRICE. The hypothesis that the owner of a large house may not be willing to pay very much for an additional 100 square feet of area as compared to an owner of a small house, will hold provided α_2 has a negative sign and is significantly different from zero. The composite variable (AREA·LOTSIZ) is the interaction term designed to measure the extent to which LOTSIZ affects the marginal effect of area on price. If α_4 is statistically insignificant, then we can conclude that the additional price of an extra unit of area does not depend on the lot size.

A second formulation which can also be used to test the hypotheses described earlier is the following:

$$\text{PRICE} = \beta_o \cdot \text{AREA}^{\beta_1} \cdot \text{LOTSIZ}^{\beta_2} \cdot Z \qquad (6.3)$$

This is the well-known Cobb-Douglas (or double-log) formulation which can also be written as

$$\log(\text{PRICE}) = \log\beta_o + \beta_1 \log(\text{AREA}) + \beta_2 \log(\text{LOTSIZ}) + \log Z \; . \qquad (6.4)$$

It is readily noted that

$$\beta_1 = \frac{\partial \log(\text{PRICE})}{\partial \log(\text{AREA})}$$

β_1 is thus the constant elasticity of the price with respect to the living area. It is approximately the percentage change in price for a unit percentage change in the area. The marginal effect of area on price is given by

$$\frac{\partial \text{PRICE}}{\partial \text{AREA}} = \beta_o \beta_1 \text{AREA}^{\beta_1 - 1} \text{LOTSIZ}^{\beta_2} \cdot Z \qquad (6.5)$$

If $0<\beta_1<1$, then the hypothesis that the marginal effect of area on price will diminish when the area becomes larger will be substantiated. The interaction between LOTSIZ and AREA is also captured in (6.3).

It should be pointed out that, while both (6.1) and (6.3) enable us to test the hypotheses specified earlier, in (6.1) six unknown parameters are to be estimated. This means a loss of six degrees of freedom whereas eqation (6.3) involves a loss of only three degrees of freedom. Furthermore, there is likely to be substantial correlation between the three variables AREA, $(\text{AREA})^2$ and $(\text{AREA}\cdot\text{LOTSIZ})$. This multicollinearity is likely to make inferences regarding the significance of individual coefficients more difficult. This problem is less serious in the Cobb-Douglas formulation, since each attribute appears only once. With more attributes, there are more nonlinear and interaction effects, and this difference becomes even greater. The double log formulation captures these effects while at the same time reducing multicollinearity and economizing on the number of parameters to be estimated, thus increasing the power of tests (in the statistical sense). For these reasons the emphasis throughout this study will be on the double log formulation even though it is somewhat less flexible than (6.1). We do, however, present the results of other formulations as well.

In the following paragraphs we discuss briefly the reasons for including the other explanatory variables in the analysis and we suggest in some cases how they might enter the statistical model.

Lot size less area: To separate the influences on price of the living area from that of the size of the yard we have obtained the yard size which is measured as the lot size less the living area.

Age: The age of the house would also be important in determining its price. Other things being equal, a newer house would cost more, and hence, would also be assessed more. Would the market value decline at an increasing rate with age or at a decreasing rate? Emerson [4] has argued that the market value of the residence declines at an increasing rate with age. Let P be the current price of the property, and let B be the value of the annual flow of benefits it yields. For simplicity, this flow is assumed constant over the total useful life of the property, which we call D. Finally, let A be the current age of the residence, and let r be the relevant real discount rate. Then the relationship between the current price and the annual flow of benefits is given by

$$P = B \int_{0}^{D-A} e^{-rt} dt = \frac{B}{r} [1 - e^{r(A-D)}]. \qquad (6.6)$$

It is easily shown that $\partial P/\partial A < 0$ and $\partial^2 P/\partial A^2 < 0$. Thus, the value of a property declines with age at an increasing rate. In this study, age enters the relation in the form $1 - \exp[r(A-D)]$ or its logarithm, and we have alternatively assumed that $D = 50$, 100, and 150 years, and that $r = .02$, .04, .06. Thus, the relationship between price and age is specified as follows:

$$\begin{aligned} \log(\text{PRICE}) &= \alpha_A \log \{1 - \exp[r(A-D)]\} + Z \quad \text{or} \\ \text{PRICE} &= \beta_A \{1 - \exp[r(A-D)]\} + Z. \end{aligned} \qquad (6.7)$$

It is evident from (6.6) that the double log formulation is more appropriate here also.

Sale date: The date of sale has also been incorporated as one of the independent variables. A more recently sold home is likely to have a higher market value. The sale date is measured in fractional years. For example, March 1970 is denoted by 70.25. Thus, a larger value for this variable represents a more recently sold house.

Quality: Besides age, the quality of construction is also important in determining the value of a house. The higher the quality, the greater the market value of the house. The quality of the construction was rated as follows: Poor, average, good, excellent and luxury. These were translated into numerical scores with poor = 1, average = 2, and so on, with excellent and luxury getting the same score. This is evidently not a satisfactory procedure, because a unit score increase from poor to average may have a much different increase in value than the same unit score increase from good to excellent. To some extent, this can be taken into account by entering quality nonlinearly in the functional form. An alternative is to assign a dummy variable to each of the types of quality. In general we have avoided using too many dummy variables in this study because the large number of qualitative variables would have meant a substantial loss of degrees of freedom, especially with interaction terms.

Condition: It is evident that a house maintained in good condition is likely to be more valuable than one which is not. This variable also is in qualitative form with ratings poor, fair, average, good and excellent. As for the quality variable, this has been converted to a numerical score with poor = 1.

Bedrooms, bathrooms and other rooms: The number of bedrooms, bathrooms and other rooms are of obvious importance in affecting the residential property values. Other rooms are defined as total number of rooms (excluding kitchen and baths) less number of bedrooms. These will thus be living room, den, playroom, family room, etc.

Garage space: This variable is measured as 1 + number of cars which can be parked inside the garage. A house with no separate garage will thus have a score of one.

Number of floors: It is clear that for a residence with a given lot size and area, the value will depend on the number of stories it has. A two-story house would mean a stronger and hence a more expensive foundation, and would also have more outside area. We may therefore expect a positive relationship between price and number of floors. This variable has been defined as a dummy with the value of one for a residence with more than one floor. Because it is not possible to take the logarithm of a dummy variable, it is specified additively in a linear formulation and multiplicatively in the Cobb-Douglas form (or equivalently, additively in the double-log form). Thus, for instance, the relationship between price and FLOORS can be specified as follows:

$$\log(\text{PRICE}) = \alpha_F \text{ FLOORS} + Z$$

or

$$\text{PRICE} = \beta_F \text{ FLOORS} + Z \, . \tag{6.8}$$

This procedure has been adopted for all the dummy variables used in the study. The interaction terms, however, are specified differently. For example, the interaction between FLOORS and AREA is specified in the linear form as (FLOORS·AREA ≡ AFLOOR) whereas in the double log form it is specified as (FLOORS·log AREA ≡ LARFLR). The latter form simply states that the elasticity of PRICE with respect to AREA depends on the number of floors.

Fireplace: A residence with one or more fireplaces is likely to be more valuable than one without a fireplace. This variable is measured as 1 + number of fireplaces in the residence.

Built-in appliances: This refers to the presence or absence of a built-in dishwasher and/or range-oven, but has been translated into a numerical score with one for a house with no range-oven or dishwasher, two for a residence with only one of the two built-ins and three for a house with both. Houses vary substantially in the quality of the appliances. For instance, a residence may be equipped with a self-cleaning oven which certainly costs more. However, since such data are not available, only the above scores are used.

Air-conditioning: In Los Angeles where smog is often a serious problem, many home owners prefer to air-condition their homes and hence, we would expect air-conditioned houses to have a higher market price. A score of one was given to a home with no air-conditioning, two for a residence with either a wall air-conditioning or an evaporative cooler system, and three for a home with central air-conditioning.

Pool: Homes which had swimming pools had either a heated pool or ordinary pool. To distinguish between these, a score of three was assigned to a heated pool, two for a non-heated pool, and one for a home without a swimming pool.

Remodeling: Remodeling very often augments the value of a property. A house which has not been remodeled was rated one, a residence completely remodeled was rated three, and others in between (kitchen, bath or both remodeled) were assigned a score of two. Again these scores are inadequate variables because they do not take into account the extent and quality of remodelling.

Front-footage: The front-footage of a lot, measured in feet, has also been used in this study to test whether this variable significantly affects the price of the property. Because of a possible high correlation between the size of the lot and the front-footage, it may be difficult to separate the influence of this variable.

Corner lots: Corner lots may exert both positive and negative influences on house value. On the one hand a corner lot has greater accessibility to the street and increased privacy due to having only two neighbors instead of three. However, a corner lot may also have the disadvantage of greater exposure to traffic noise and fumes, and having pedestrians cut across the property. This variable is measured as a dummy variable with a corner assuming a value of one.

Cul-de-sacs: A residence located in a cul-de-sac may be more valuable because of reduced traffic and greater privacy. This variable is also measured as a dummy with one for cul-de-sac.

View lot: A house with a good view will obviously have a higher market value than one without. Although a rating scale giving various types of view would be appropriate, this variable is only available as a dummy with one for a house with a good view.

Main street: Similar to a corner lot, a house located on a main street may have both desirable and undesirable elements, although the undesirable features are likely to dominate. A house located on a main street, takes the value of one for this dummy variable.

Odd lot: It is hypothesized that, other things being equal, a residence situated in an odd-shaped lot will have a different value as compared to "normal" lots. To test this hypothesis, we have constructed a variable called ODDLOT which is obtained as follows. If we take the view that a normal lot is more square shaped than an odd lot, then the ratio of the perimeter of the lot to the square root of lot size is a rough measure of the oddness of a lot. If all the lots in the neighborhood are odd by this criterion, then there may be no difference in property values due to this particular variable. We therefore consider the absolute value of the deviation of this ratio from its mean for the entire sample. More formally, this variable is defined as follows:

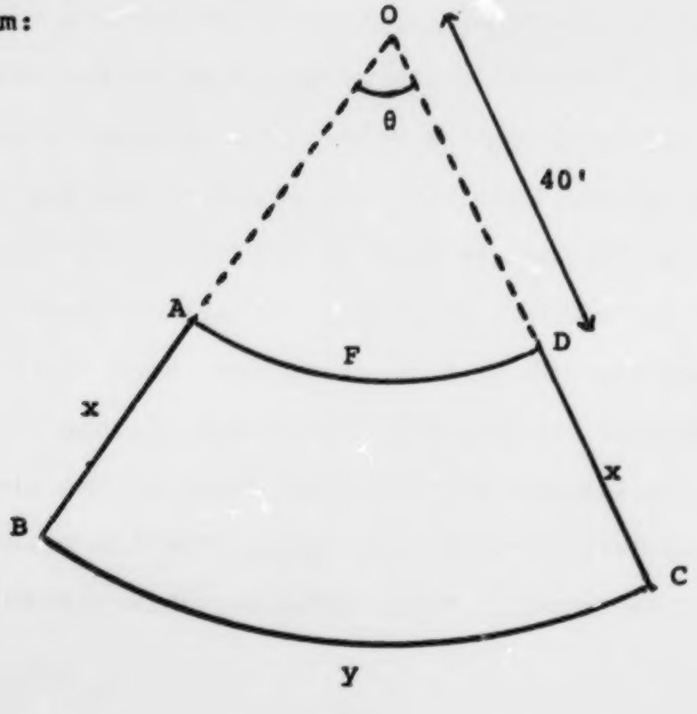
$$\text{ODDLOT} = \left| \hat{P}/\sqrt{S} - \bar{R} \right| \qquad (6.9)$$

where $\hat{P}$ is the estiminated perimeter of the lot, S is the lot size and $\bar{R}$ is the mean of $\hat{P}/S$ for the sample residences near a given fill. The perimeter, $\hat{P}$, is estimated as follows:

(a) If the lot is a corner lot, then $\hat{P}$ is twice the front footage (F).

(b) In the case of a lot not in a corner or a cul-de-sac, $\hat{P}$ is estimated as 2 [F + S/F], on the assumption that it is a rectangular lot.

(c) If a lot is situated in a cul-de-sac, we assume that it has the shape indicated in the following diagram:



The perimeter is given by $\hat{P} = F + 2x + y$. We also assume that an average cul-de-sac has a 40 foot radius to the lot. If θ is the angle, in radians, made by the sides of the lot as indicated above, then $40\theta = F$ and $y = (40+x)\theta$. To obtain x, we use the lot size S which is the area ABCD. We have

$$S = OABCDO - OADO = \frac{1}{2}(40 + x)^2\ \theta - \frac{1}{2}\ 40^2\ \theta.$$

This gives the following quadratic equation and solution for x.

$$x^2 + 80x - 25/\theta = 0$$

$$\hat{x} = -40 + \sqrt{1600+25/\theta}$$

Therefore,

$$\hat{P} = F-80 + (2+F/40)\sqrt{1600+80S/F} \qquad (6.10)$$

In double log formulations, LODDLT ≡ log (ODDLOT) is used as an explanatory variable.

Downpayment: The downpayment made at the time of purchase of the property may influence its price, although it is not clear what its direction of effect is likely to be, if any. Downpayment has been measured as a fraction of sale price.

Lease hold: To the extent that owners who reside in the home take better care of the residence, a house rented out is likely to fetch a smaller price than one in which the owner is living. It would therefore be desirable to included a dummy variable which takes the value one if the property is leased. However, since none of the sample houses were rented, this variable is not used in the study.

Condominium: A house in a condominium can be expected to have a lower value than a similar single family house, because the latter has greater privacy. This variable is also measured as a dummy which takes the value one if the residence is in a condominium and zero otherwise. This variable also is omitted because none of the sample residences were in a condominium.

Distance to shopping centers: The distance to the nearest shopping center is likely to have a non-linear effect on property values. Being too close to the shopping center is generally not desirable because of traffic congestion, noise and fumes. Similarly, being too far away is also not desirable because of increasing commuting costs. We have therefore included the distance to the nearest shopping center as one of the explanatory variables.

Distance to the nearest park: This variable will measure the premium, if any, that people are willing to pay to be close to a neighborhood park. Here also, there may be a non-linear effect.

Distance to the nearest freeway ramp: Being not too far away from a freeway entrance is also desirable because of greater accessibility to other parts of the city. However, being closer to the freeway may also mean greater noise associated with it.

Distance to the nearest point of the freeway: In some instances, a residence may be located very near the freeway itself, even though the access to it may be some distance away. This is not a desirable feature because of increased noise and possible visual pollution.

Distance to the sanitary landfill: This variable is of major interest to this study. If it is true that homeowners are adverse to being close to a landfill, however sanitary it may be, then we will expect that, ceteris paribus, the further away a house is located from a fill, the higher its value. In other words, we would expect a positive coefficient for this variable. It should, however, be pointed out that the effect of the sanitary landfill would also depend on the future use to which it will be put once the landfill has been closed. For instance, if the landfill is expected to be turned into a golf course or other recreation area after a few years, then the effect of the landfill could be positive if the residents are willing to put up with current disamenities arising from the landfill in order to enjoy future benefits.

Distance to the dump truck route: Being close to the route the trucks take to carry waste to the landfill is clearly undesirable because of the added noise and possible damage to health and property from the exhaust fumes emitted by the trucks.

View of the sanitary landfill: To the extent that people are willing to pay a higher premium for a better view from their residence, a direct view of the fill may be quite undesirable. It may be, however, that expected future benefits of a view of the landfill when it would become a recreation area will outweigh present disamenities. This variable is measured as a dummy with a value of one if the residence has a direct view of the landfill.

Degrees from prevailing downwind: An undesirable feature of a landfill is the possibility of bad odor emitting from it. Houses that are downwind of the landfill may receive more odor and dust than other houses which may be closer to the fill site but not downwind. For this reason, we have measured the number of degrees away from the prevailing downwind direction that the residence in question is situated.

Distance to other disamenities: We also measured the distance to other disamenities that may be present in the nieghborhood, For instance, Tujunga has a gravel pit nearby which is clearly a disamenity.

Interaction terms: The list of explanatory variables also includes several interaction terms. For instance, the effect of the front-footage of a house on property value is likely to depend on whether the house is on a corner lot or is situated in a cul-de-sac. Typically, houses in a cul-de-sac have smaller front-footage and much larger back footage. The fact that it has a smaller front-footage may not decrease its value because it is situated in a cul-de-sac. Another interaction term takes account of the joint effect of lot size and pool. The pool variable does not measure the size of a pool, which may be important because a larger pool may increase the value of the house. A larger pool is unlikely unless the lot size is big. Thus, there is a possibility of an interaction between lot size and pool. Another interaction used here is that between the living area and the number of floors. The elasticity of price with respect to the area may depend on the number of floors in the house. Table 6.2 includes all the interaction terms used in the analysis and the corresponding names.

D. EMPIRICAL RESULTS

In this section we present the results of the study of the effects of sanitary landfills on the four sanitary landfills in Los Angeles county. The sample sizes for each of the fills were as follows: Palos Verdes, 447; Tujunga, 279; Sheldon-Arleta, 179; Calabasas, 61. Because the characteristics of each neighborhood are quite different, the estimation has been done for each fill separately. In each case double log and linear relations using price and assessed value as the dependent variables and a long set of independent variables, were estimated for the different useful lifetimes (D) and discount rates (r) specified in Section C in defining the AGE variable. The values of D and r which gave the "best" fit in terms of the highest $\overline{R}^2$ and F statistics were chosen. Although there were some exceptions, it was found that in most cases D = 150 and r = .02 (as defined by the age variable AGE215 or LAG215) gave the best fit. For the sake of convenience and comparability these values have been used throughout the rest of the estimation for all landfills and all other dependent variables. A comparison of the average values for a number of variables for each of the four sites is given in Table 6.3. The results of the analysis for each fill are presented in the following four sections.

Palos Verdes

The Palos Verdes Landfill is one of the largest sanitary landfills in Los Angeles County. It handles the largest yearly volume of refuse (approximately 1,600,000 tons) and covers an area of approximately 220 acres (Table 6.1). It is situated at the base of the eastern slope of the Palos Verdes Peninsula, a mountainous region bordering the Pacific Ocean in the southwestern corner of Los Angeles County. Surrounding and overlooking the landfill site to the west and south are the upper-income residential communities of Rolling Hills and Rolling Hills Estates. The terrain in this area is one of partially wooded, sharply rising foothills, steep narrow canyons, and small winding roads. Consequently, many of the homes in this area have an unrestricted view of the landfill. The atmosphere in these communities is quiet, spacious, well-groomed, and surburban. This ambiance offers a sharp contrast to the commercial and industrial sections of Torrance which borders the site to the north and west.

The Palos Verdes Landfill began operations in 1957 and is scheduled for completion in 1977, at which time a golf course is planned for the site. Another portion of this site which was completed some time ago has already been turned into a botanical garden.

The average sale price of the 447 sample residences was $50,110 with an average assessed value of $43,545. The mean size of the lot is 12,908 square feet and the living area is 1,843 square feet. In terms of house values, Palos Verdes is clearly the most expensive of the four neighborhoods under study. In lot size, number of bedrooms and bathrooms, however, Calabasas dominates the other three communities. It is interesting to note that for the two low value neighborhoods, Tujunga and Sheldon-Arleta, the ratio of assessed value to sale price was much higher than that of the wealthy neighborhoods of Palos Verdes and Calabasas.

Tables 6.4 and 6.5 present the estimated coefficients and their t-statistics for PRICE, ASSVAL, log(PRICE) and log(ASSVAL). They indicate that the explanatory variables used in this study explain 90 percent of the variation in price, 81.3 percent of the variation in assessed value, 90 percent of the variation in log(PRICE) and 80 percent of the variation in log(ASSVAL). Considering that this is a cross-section of residences with a fairly large sample, the goodness of fit is quite good. It is not surprising, however, that a number of independent variables are statistically insignificant (at a 95 percent confidence level). With a large list of highly related variables we can expect multicollinearity to seriously affect the results making it difficult to make inferences about individual coefficients. In order to examine the sensitivity of the coefficients to alternative specifications of the relationships, several different formulations were tried, although in each case several key variables (such as area, lotsize, bedrooms and bathrooms) were retained regardless of whether they were statistically significant. Table 6.6 presents the coefficients for log(PRICE) and log(ASSVAL) for one such formulation. Most of the coefficients in Table 6.6 are significant. (We employ two-tailed tests at the 5% level.) While $\bar{R}^2$ does not change much between Tables 6.4 and 6.6, the F statistics (which test the joint significance of all the independent variables) more than double for both dependent variables. The evident reason for this is the substantial gain in degrees of freedom (D.F.) in Table 6.6.

The variables describing the sanitary landfill are of maximum interest for this study. Among the fill variables the wind direction (LGWIND) was the only one statistically insignificant. The most interesting result is that both distance to the sanitary landfill and view of fill showed opposite signs from what was initially expected. For instance, houses with a direct view of the fill (16 percent of the sample) had a significantly higher market price and interestingly enough, were also assessed higher compared to similar residences without a view of the fill. This conclusion holds for both linear and double log formulations and even if the full list of explanatory variables are included (i.e., even with substantial multicollinearity, which is likely to raise estimated standard errors and thus lower t-statistics). Similarly, houses closer to the sanitary landfill (the average distance is a mile) have higher prices, as indicated by the fact that the distance to the fill has a negative and significant coefficient both in the linear and double log formulations. The elasticity of price with respect to distance to fill is -6.9 percent (Table 6.6). This means that if the distance from the fill is doubled keeping other characteristics of a residence the same, then its price will decrease by 6.9 percent. Similarly, a direct view of the fill tends to raise the sale price an average of 2.8 percent.

The explanations for this counter intuitive result are not difficult to find in the case of Palos Verdes. As mentioned earlier, a portion of the landfill has already been converted into a lovely botanical garden. The rest of the sanitary fill is expected to become a golf course in 1977. Since Palos Verdes is an upper-income area, one might expect actual and potential residents to place a high value on proximity to a golf course or botanical garden. The net value of proximity to the landfill must depend on the present discounted values of (1) long-term proximity to the garden, (2) a few years of fill-related disamenities, and (3) long-term proximity to the golf course after the fill is converted. One explanation for our results is that the relevant discount rate is low, so that the third value is large enough relative to the second to make the sum of all three positive.

Although home owners near the Palos Verdes landfill are willing to pay higher prices even though there is a direct view of the fill or the residences are closer to the fill, they apparently do regard as costs the noise, visual pollution, congestion and air pollution associated with the trucks that carry solid waste to the fill. The distance to the truck route showed a significant positive coefficient indicating that the farther away from the truck route a property is situated, the higher its value. This conclusion also holds for the assessed value and is independent of the functional forms used to formulate the estimation models (Tables 6.4 through 6.6). The elasticity for distance to the truck route was 0.0281 indicating that a residence situated at a distance twice that of another residence of similar characteristics has a 2.81 percent higher price on average. However, the effects of being near or having a view of the landfill are larger than the effect of being near the truck route which suggests that, for the Palos Verdes area, the presence of the sanitary landfill has not been detrimental to property values but in fact has been beneficial.

While the focus for this study is on the variables associated with the presence of the sanitary landfill, other characteristics of a property are also of considerable interest. In interpreting the effects of other variables on price and assessed value, we have used only the double log formulation which was justified in Section C as being more powerful. The results are presented in Table 6.6. The variables which significantly affect the sale price of a residence are discussed first.

It was hypothesized in Section C that lot size and living area will both have positive but declining effects. In other words, additions to either of the two variables would increase property values but at a decreasing rate. The results support this hypothesis. The price elasticity with respect to area was 49.9 percent whereas that for lot size was only 5.7 percent (Table 6.6). Since both are less than 100 percent, it follows that there is diminishing marginal returns to the size of the lot and living area; that is, the owner of a large house will be willing to pay less for an extra 100 square feet area (or lot size) than the owner of a smaller residence. When the size of the yard was used instead of the lot size, the elasticity for area became 55.3 percent and that for yard size was 4.1 percent.

Among bedrooms, bathrooms and other rooms (excluding kitchen), only the number of bathrooms had a statistically significant coefficient. A doubling of the number of bathrooms would increase the price by 14.1 percent (Table 6.6). The number of bedrooms did not have a significant coefficient, which implies that an additional bedroom (keeping number of bathrooms, living area, lot size and all the other characteristics of the residence constant), does not affect the price of a property.

As can be expected, a more recently sold house, as indicated by a higher value for SALDAT, had a higher market price. In fact, this variable had the highest t-statistic among all the independent variables. The dummy variable for a view lot is also significant implying that residences with a good view had a higher market value than similar houses without a view. On average, view adds 2.8 percent to the price of a house. The condition of maintenance of a property was also important in explaining the variation in price. A doubling of the CONDN rating increased the average price by 12 percent. Another significant variable was the down payment as a fraction of the sale price. A doubling of this fraction would increase the sale price by 15.6 percent. This suggests that buyers are willing to pay the higher mortgage rates associated with higher loan to market value ratios only if they get a break on the price of the house.

It was mentioned earlier that a house situated on a main street will have both desirable and undesirable elements. The undesirable features -- the noise, air pollution and hazards associated with the increased traffic -- are likely to dominate any advantage due to nearness to shopping areas, bus routes or schools. In the Palos Verdes area, a main street location means reduced property values as shown by a significant negative coefficient for this dummy variable. A house located on a main street will only sell for approximately 93.5 percent of a similar house not on a main street (Table 6.6). Also consistent with our expectations is the finding that homes nearer a park are more valuable than similar homes farther away. The distance from the park shows a significantly negative coefficient, although the magnitude of the elasticity itself is not large. A doubling of the distance from the park would reduce market values by by an average of 2.8 percent.

Residences with a swimming pool do have a higher sale price as indicated by the fact that the variable LGPOOL has a significant positive coefficient. Having a heated pool raises the market price even more. The quality of construction LGQUAL, however, does not have a significant coefficient in Table 6.6, but if other variables with a low t are excluded, LGQUAL became significant, which suggests that its statistical insignificance resulted from the high correlation between quality of construction and other variables.

A number of variables in Table 6.4 which do not have significant coefficients were tested for joint significance with other variables with insignificant coefficients. None of the joint F-tests involving CORNLT, CULDSC, LODDLT, LGAPPL, LFRONT (and its interaction terms with corner lot and cul-de-sac) were significant and these variables were excluded from Table 6.6.

All the results interpreted above refer only to the determinants of the sale price of the residences in the Palos Verdes area. It is of considerable interest to examine the variables that are of significance in explaining the assessed value of the property as well. To a large extent there will be a high correlation between the sale price and the assessed value of a property because past sale price of the same or a similar house in the neighborhood is usually taken into account by the assessor in setting the value of a property for tax purposes. However, the criteria used by the assessor need not coincide with those which determine the market demand for residential property.

It is of interest to note that for the Palos Verdes area as well as the other three neighborhoods, the list of variables that significantly explain the variation in sale price is not the same as that of variables explaining the variation in the assessed value of the property. For instance, the condition of maintenance of the property, down payment, main street location and distance to the nearest park, all had statistically significant coefficients for the dependent variable LPRICE, but none of these variables significantly affected LASSVL. On the other hand, fireplace, the oddness of a lot and the number of degrees away from the downwind from the fill, significantly affect the assessed value of the property but not the sale price. As one might expect, the more the number of fireplaces the higher the assessed value. Also, the variable LODDLT which measures the oddness of a lot has a significantly negative regression coefficient. In other words, the more odd the shape of a lot (as measured in this study) relative to other lots in the neighborhood, the less the assessed value of the property. The variable

LGWIND, which did not significantly affect the sale price of a property, has a positive and significant coefficient for the assessed value dependent variable LASSVL. This, of course, does not imply that the assessor's office consciously takes the degrees away from wind (or the oddness of the lot) into account when setting the assessed value of a property.

It is also of interest to compare how a variable which significantly affects both the assessed value and the sale price differs in the respective elasticities. Some of the differences are quite small. The direct view of the fill, for example, increases prices by 2.8 percent whereas it increases the assessed value an average of 3.1 percent. A doubling of the distance from the fill would decrease the sale price by 6.9 percent whereas it would decrease the assessed value by only 4 percent. The elasticity with respect to the distance to the dump truck route was .036 for assessed value as compared to .028 for the price.

The most significant difference between the regressions for the sale price and those for the assess value is in the SALDAT variable. This variable had a significant but negative coefficient for the assessed value but a positive and very highly significant coefficient for price. The coefficient from the price regression is easy to interpret: since the property prices have been rising steadily for many years, the more recent the date of sale for which the price was recorded, the higher is the price. The coefficient from the assessed value regression does not have so obvious an explanation. One possibility is that assessed values of properties that are not sold in any given year rise more rapidly than market values. But since assessments are supposed to reflect market values, whenever a property is sold, the assessor must equate assessed value with price. Consequently, the more recently a property is sold the less will the assessed value have risen relative to market value and the lower the assessed value will be. If assessed values rose in proportion to market values, then the coefficient on SALDAT would not be significantly different from zero.

Another difference between the assessed value and price regressions is in the age variable. A newer house (as indicated by a larger value for AGE215 and LAG215) had a significantly higher sale price than a similar, but older, house. However, for the assessed value regressions, the age variable did not have statistically significant coefficients. The number of bathrooms also showed a substantial difference in the effect on price and assessed value. For example, a doubling of the number of bathrooms would increase the assessed value by an average of 7.8 percent, whereas in the case of the sale price, the increase would have been as much as 14.1 percent.

A number of independent variables had to be excluded from the analysis because they could not be measured for the Palos Verdes area for a variety of reasons. These were: Distance to the nearest freeway and the nearest off ramp (there is no freeway nearby), distance to the shopping center and the dummy variables for condominium and leasehold.

Table 6.3 MEANS AND STANDARD DEVIATIONS (IN PARENTHESES) OF SELECTED VARIABLES

Variable	Palos Verdes		Tujunga		Sheldon-Arleta		Calabasas	
PRICE ($)	50,110	(14,706)	22,962	(4,474)	24,097	(5,164)	44,880	(6,360)
ASSVAL ($)	43,545	(11,571)	20,793	(3,801)	21,772	(4,869)	38,785	(6,045)
LOTSIZ (sq. ft.)	12,908	(9,296)	7,285	(4,401)	7,382	(1,909)	9,994	(1,890)
AREA (sq. ft.)	1,843	(512)	1,149	(275)	1,228	(336)	2,588	(433)
Bedrooms	3.4	(.72)	2.7	(.57)	2.9	(.75)	4.0	(.86)
Bathrooms	2.1	(.51)	1.3	(.40)	1.4	(.49)	2.7	(.50)
Other rooms	3.3	(3.4)	2.5	(.67)	2.6	(.61)	3.7	(.51)
Viewlots (%)	36.2		None		None		None	
Leased (%)	0.2		None		None		None	
Corner lot (%)	21.5		15.[illegible]		[illegible].6		3.3	
Main street (%)	2.9		12.5		[illegible].9		None	
Cul-de-sac (%)	6.0		2.5		None		None	
View of fill (%)	16.1		None		None		None	
DFILL (ft.)	5,290	(2,000)	3,059	(1,160)	2,633	(964)	3,007	(424)
DTRUK (ft.)	550	(1,351)	3,190	(1,081)	1,550	(682)	621	(418)
DPARK (ft.)	3,899	(1,664)	4,592	(1,338)	2,255	(1,348)	None	
DJUNK (ft.)	9,400	(3,806)	2,244	(753)	3,470	(821)	None	
DFRWY (ft.)	None		4,980	(1,231)	1,733	(1,156)	1,774	(471)
DRAMP (ft.)	None		5,021	(979)	2,179	(943)	1,907	(326)
Sample Size	447		279		179		61	

Table 6.4 NAME OF LANDFILL: PALOS VERDES

Independent Variables	Dependent Variable*			
	LPRICE		LASSVL	
CONST	-1.3343	(-2.79)*	7.2940	(11.41)*
LAG215	4.8636	(4.44)*	2.1362	(1.56)
LLOTSZ	0.0422	(2.36)*	0.0919	(4.08)*
LGAREA	0.4891	(12.66)*	0.5449	(11.17)*
LBDRUM	-0.0123	(-0.43)	-0.0489	(-1.36)
LBTHRM	0.1503	(4.92)*	0.0999	(2.59)*
LOTHRM	-0.0024	(-0.16)	0.0056	(0.30)
SALDAT	0.0553	(12.47)*	-0.0168	(-3.13)*
LGPOOL	-0.1958	(-0.83)	0.5089	(1.70)
LODDLT	0.0122	(0.62)	-0.0791	(-3.18)*
CORNLT	0.1954	(0.92)	-0.5147	(-1.93)
LFRONT	0.0153	(0.56)	-0.0791	(-2.28)*
CULDSC	0.0890	(0.68)	-0.0258	(-0.16)
CRLFRN	-0.0401	(-0.96)	0.1013	(1.91)
CLLFRN	-0.0174	(-0.52)	0.0038	(0.09)
LGAPPL	0.0132	(0.91)	0.0377	(2.05)*
LAIRCN	-0.0756	(-1.32)	0.0611	(0.85)
VIEWLT	0.0251	(2.74)*	0.0196	(1.69)
LREMOD	0.0272	(1.04)	0.0115	(0.35)
LFIRPL	0.0058	(0.27)	0.0563	(2.07)*
LGARAG	-0.0153	(-0.81)	0.001	(0.00)
FLOORS	-0.4892	(-0.51)	0.6254	(0.52)
LARFLR	0.0623	(-0.51)	-0.0868	(-0.57)
DOWNP	0.1495	(2.77)*	0.1082	(1.59)
LGQUAL	0.0465	(1.77)	0.0102	(0.31)
LCONDN	0.1169	(5.25)*	0.0112	(0.40)
LLOTPL	0.0295	(1.18)	-0.0450	(-1.42)
LDPARK	-0.0301	(-2.34)*	-0.0078	(-0.48)
LDJUNK	-0.0284	(-0.80)	-0.564	(-1.26)
MAINST	-0.0611	(-2.46)*	-0.373	(-1.19)
LDFILL	-0.0581	(-2.85)*	-0.0247	(-0.96)
LGWIND	-0.0253	(-0.68)	0.1244	(2.64)*
LDTRUK	0.0260	(5.39)*	0.0359	(5.89)*
VIEWFL	0.0280	(2.15)*	0.0383	(2.33)*
$\bar{R}^2$	0.900		0.798	
F	121.974		54.427	
D.F.	413		413	

*The figures in parentheses are t-statistics. Asterisks indicate significance at the 5% level on a two-tailed test.

Table 6.5 NAME OF LANDFILL: PALOS VERDES

Independent Variables	Dependent Variable*			
	PRICE		ASSVAL	
CONST	-4119.08	(-6.09)*	2470.91	(0.04)
AGE215	2607.18	(4.00)*	65,976.3	(0.95)
LOTSIZ	0.0014	(1.77)	0.2363	(2.86)*
AREA	0.1397	(12.91)*	14.3407	(12.40)*
BDROOM	-7.0247	(-1.55)	-808.384	(-1.67)
BTHRUM	36.4577	(4.71)*	2078.66	(2.51)*
OTHRUM	0.1037	(0.15)	29.7112	(0.41)
SALDAT	24.9603	(10.21)*	-834.302	(-3.71)*
POOL	13.3779	(1.74)	3194.24	(3.88)*
ODDLOT	-0.0012	(12.14)*	-0.2136	(-3.71)*
CORNLT	20.8133	(1.38)	158.033	(0.10)
FRONT	-0.1778	(-1.66)	-30.7953	(-2.70)*
CULDSC	3.7293	(0.20)	1391.79	(0.71)
CRFRNT	-0.0401	(-0.33)	19.9589	(1.52)
CLFRNT	-0.2442	(-0.78)	-45.6136	(-1.36)
APPL	-0.9563	(-0.23)	500.783	(1.14)
AIRCON	-21.5588	(-1.24)	1272.81	(0.68)
VIEWLT	9.0710	(1.80)	663.728	(1.23)
REMODL	9.5899	(1.04)	-721.489	(-0.74)
FIREPL	7.3473	(1.16)	1290.04	(1.91)
GARAGE	-5.0673	(-1.01)	326.642	(0.61)
FLOORS	-86.3110	(-1.24)	1913.98	(0.26)
AFLOOR	0.0371	(1.38)	-2.0199	(-0.70)
DOWNP	80.8308	(2.70)*	3971.53	(1.24)
QUALTY	9.9332	(1.76)	524.130	(0.87)
CONDN	22.7120	(5.09)*	383.273	(0.80)
LTSZPL	0.0008	(1.67)	-0.0803	(-1.61)
DPARK	-0.2824	(-1.07)	-52.9937	(-1.88)
DJUNK	-0.0610	(-0.91)	0.3238	(0.05)
MAINST	-22.6179	(-1.65)	-607.202	(-0.42)
DFILL	-0.5202	(-3.19)*	-51.5351	(-2.95)*
WIND	0.0128	(-.07)	26.3665	(1.34)
DTRUCK	1.6723	(7.53)*	164.611	(7.03)*
VIEWPL	16.1407	(2.18)*	1951.22	(2.47)*
$\bar{R}^2$	0.899		0.813	
F	120.794		59.875	
D.F.	413		413	

*The figures in parentheses are t-statistics. Asterisks indicate significance at the 5% level on a two-tailed test.

Table 6.6 NAME OF LANDFILL: PALOS VERDES

Independent Variables	Dependent Variable*			
	LPRICE		LASSVAL	
CONST	-1.4182	(-4.24)*	6.4364	(12.77)*
LAG215	4.7036	(4.70)*	1.4125	(1.14)
LLOTSZ	0.0568	(5.06)*	0.0612	(4.07)*
LGAREA	0.4992	(13.75)*	0.5811	(13.51)*
LBDRUM	-0.0024	(-0.09)	-0.0508	(-1.51)
LBTHRM	0.1405	(4.90)*	0.0784	(2.15)*
LOTHRM	-0.0002	(-0.01)		
SALDAT	0.0524	(18.93)*	-0.0171	(-4.02)*
VIEWLT	0.0283	(3.19)*	0.0262	(2.34)*
DOWNP	0.1563	(2.96)*		
LCONDN	0.1200	(5.46)*		
LDPARK	-0.0284	(-2.46)*		
MAINST	-0.0677	(-2.81)*		
LDFILL	-0.0688	(-5.30)*	-0.402	(-2.45)*
LGWIND	-0.0080	(-0.25)	0.1548	(4.71)*
LDTRUK	0.0281	(6.53)*	0.0361	(6.79)*
VIEWFL	0.0277	(2.25)*	0.0306	(1.95)
LGQUAL	0.0395	(1.56)		
LGPOOL	0.0810	(6.73)*	0.0835	(5.42)*
LODDLT			-0.0209	(-3.13)*
LFIRPL			0.0528	(2.58)*
$\bar{R}^2$	0.900		0.794	
F	225.161		123.930	
D.F.	428		432	

*The figures in parentheses are t-statistics. Asterisks indicate significance at the 5% level on a two-tailed test.

Tujunga

This is a privately operated landfill using what was at one time a sand and gravel pit. It is located on Tujunga Avenue, only about two miles from the Sheldon-Arleta disposal site. This site comprises 66 acres and handles approximately 370,000 tons a year of solid waste volume (Table 6.1).

Homes along two streets, Strathern and Irvine, have a direct view of the landfill, but they also have a view of other industry in the immediate vicinity. There are operating gravel pits bordering on two sides of the landfill site. Many of the homes in the vicinity of this site are old and rundown. This site was started in 1962 and should be completed around 1978, at which time the owners will try to sell the site to the State or County for use as a park.

The average sale price of the 279 sample residences is $22,962 and the mean assessed value is $20,793 which are the lowest of the four sanitary landfill areas studies (Table 6.2). The average lot size, living area, number of bedrooms and bathrooms are also the smallest as compared to the other three neighborhoods. Although some homes along two streets have a direct view of the landfill, none of the sample residences had a direct view. In addition to this variable, several others had to be excluded from the analysis because of insufficient information. These were: Quality of construction, condition of maintenance, number of floors, down payment, distance to the nearest shopping center and dummy variables for view lot, condominium and leasehold.

Tables 6.7 and 6.8 present the results for regressions involving the dependent variables PRICE, ASSVAL, LPRICE and LASSVL. The goodness of fit ($\bar{R}^2$) for PRICE and LPRICE was much lower for Tujunga as compared to Palos Verdes. Only about 66 to 68 percent of the variation in these dependent variables could be explained by the independent variables measured for residences in this neighborhood. The variation in the assessed value and its logarithm is better accounted for with 81 to 82 percent explained by the model. Table 6.9 presents the estimated coefficients and their t-statistics after many of the insignificant variables have been eliminated, with the exception of the variables representing the relationship between the property and the sanitary landfill. As in the case of Palos Verdes, only the double log formulation is used in interpretation for the reasons given in Section C.

Among the fill related variables LDFILL, LDTRUK and LGWIND, only the wind direction had a statistically significant regression coefficient in the regression with LPRICE as the dependent variable. In the case of assessed value, none of the fill variables was significant. Even in the price equation, for which the wind direction had a significant coefficient, the sign is counter intuitive. The sign was negative implying that the farther away from the prevailing wind direction from the fill the less the sale price of a residence. A possible explanation for this unusual result could be the fact that there is a gravel pit on the other side which is currently in operation. Therefore, a property away from the downwind from the landfill may be closer to the wind from the gravel pit bringing dust, sand and noise. In contrast, the landfill is sanitary and is hence less likely to emit dust or odor, unlike the gravel pit. Home owners may therefore be willing to pay a higher price to avoid the wind from the gravel pit and hence be closer to the prevailing wind from the landfill. Thus a house nearer the wind direction from the sanitary landfill may carry a higher price tag.

Although the distances to the nearest freeway ramp and the nearest point of the freeway had positive coefficients with low t-ratios, the joint F-test of these two variables was quite significant. The F value of 8.34 was well above even the 1% critical value of 4.61, indicating that these two variables together have a significant effect on the sale price of residential property. The evidence shows that people are willing to pay a higher price to be away from a freeway. A doubling of the distance to the nearest point of freeway would raise the sale price by an average of 16.8 percent (Table 6.9) whereas a doubling of the distance to the nearest off ramp would raise the price by only 4.1 percent. In contrast, a doubling of the distance to the sanitary landfill will raise the price by 3.9 percent which is even lower.

As in the case of Palos Verdes we will also discuss the effects on price and assessed value of the independent variables other than those that refer to the sanitary landfill. The effects on price are discussed first. A number of independent variables showed consistently insignificant coefficients no matter what the formulation was. Even joint F-tests did not point out any significant effect of these variables on price. They are: dummy variables for corner lot, cul-de-sac and main street, fireplace, remodelling, garage space, distance to the neighborhood park and any disamenities, front footage and all the interaction of terms. Among independent variables which significantly explain the variation in prices, the age of the residence is important even at the 1 percent level with, as one might expect, newer houses having higher sale prices as compared to older residences with the same characteristics.

The elasticities of the size of a lot and the living area are also significant at the 1 percent level. As in

Palos Verdes, home owners are willing to pay much more for a doubling of the living area as compared to a doubling of the lot size. A 100 percent increase in the living area would increase the sale price by nearly 50 percent, whereas a similar increase in the size of the lot would increase the sale price by only 8.5 percent. When LYARD was used instead of LLOTSZ, the elasticities became 45.2 percent for area and 7.3 percent for size of the yard. Of the variables LBDRM, LBTHRM and LOTHRM, only LBDRUM had a significant t-statistic, and even then its sign was negative indicating that the more the number of bedrooms, keeping all other variables constant, the less the sale price. This result is counter intuitive and hard to explain. A possible reason could be that when the number of bedrooms is increased keeping the living area the same, the size of a bedroom becomes quite small, especially in a neighborhood like Tujunga in which the average living area is only 1,150 square feet. This may make the addition of a bedroom (with total area remaining the same) less desirable and hence may decrease the sale price.

The date of sale is of high significance in explaining the sale price of a residential property. As one would expect, more recently sold homes carry higher price tags. In the case of Palos Verdes, neither built-in appliances nor air conditioning significantly affected sale price. In Tujunga, however, both these attributes seemed to matter. Our estimates indicate that adding a range/oven or a dishwasher to a residence in Tujunga with neither would raise the expected sale price by 4.4 [$=100(2^{.0621}-1)$] percent (Tables 6.2 and 6.9). Installing central air conditioning in a home with no air conditioning would similarly produce a 5.4 percent increase. Adding a non-heated pool to a residence in Tujunga would raise the expected sale price by 10.1 percent, versus only 5.8 percent in Palos Verdes. The greater effect in Tujunga is not surprising, since the average sale price there is less than half that in Palos Verdes, and we would thus expect a pool to add a larger percentage to the value of a typical home.

In the case of Tujunga also there were several variables which affected the sale price significantly but had no appreciable effect on the assessed value and vice versa. As expected, the date of sale had a very high t-value (8.9) in the LPRICE case but was insignificant for LASSVL. Proximity to the neighborhood park and a main street location were important characteristics of a property influencing the assessed value, but not the sale price. The most significant difference between the regressions for LPRICE and LASSVL was in the effect of the POOL variable. Unlike the sale price, the elasticity of assessed value with respect to POOL depends on the size of the lot as evidenced by the significance of the interaction term LLOTPL. This elasticity is given by -2.1742 + 0.2624 log(LOTSIZ). Thus the bigger the size of the lot, the greater the percentage increase in the assessed value attributable to the swimming pool.

Another significant difference is in the fill variables LDFILL, LDTRUK and LGWIND. None of these variables were individually significant, nor did an F-test for their joint significance show any significance. We can, therefore, conclude that for the sample residences in the Tujunga area the presence of the sanitary landfill had no significant effect on their assessed values. Among the three variables LBDRUM, LBTHRM and LOTHRM, only the number of bathrooms had a significant regression coefficient. This is in contrast to the result for the sale price for which the number of bedrooms rather than the number of bathrooms was an important determinant. The elasticity for the number of bathrooms was 0.0989 which indicates that a 100 percent increase in their number would raise the assessed value by 9.9 percent (Table 6.9).

Unlike the sale price, the assessed value is significantly influenced by distance to the neighborhood park and a main street location. The positive coefficient of LDPARK, however, has the surprising implication that assessed value rises with distance from the park. Being on a main street reduces assessed value, by an average of 2.8 percent, as we might expect. Adding a range/oven or dishwasher to a home with neither would raise expected assessed value by 2.8 percent, even though expected sale price would increase by 4.4 percent.

Finally, the distances to the nearest freeway exit and the nearest point of the freeway were jointly (but not individually) significant, with positive but rather different coefficients. The elasticity of assessed value with respect to distance to the off ramp was 9.0 percent, while for sale price it was only 4.1 percent. In contrast, the elasticity with respect to the distance to the nearest point of the freeway was 8.1 percent for assessed value and 16.8 percent for sale price.

Table 6.7 NAME OF LANDFILL: TUJUNGA

Independent Variables	Dependent Variable*			
	LPRICE		LASSVL	
CONST	-0.7567	(-1.01)	6.2719	(11.79)*
LAG215	4.2851	(4.78)*	3.7153	(6.09)*
LLOTSZ	0.0960	(2.11)*	0.0435	(1.35)
LGAREA	0.4000	(6.54)*	0.3983	(9.18)*
LBDRUM	-0.1110	(-2.64)*	-0.0077	(-0.26)
LBTHRM	0.0850	(2.07)*	0.1100	(3.76)*
LOTHRM	-0.0407	(-1.17)	-0.0288	(-1.17)
SALDAT	0.0389	(5.91)*	0.0025	(0.54)
LGPOOL	-2.6004	(-1.63)	-2.2672	(-2.01)*
LODDLT	-0.0170	(-0.35)	0.0187	(0.54)
CORNLT	0.6247	(0.76)	-1.7309	(-2.96)*
LFRONT	-0.0062	(-0.10)	0.0444	(1.01)
CULDSC	0.4945	(0.74)	0.2513	(0.53)
CRLFRN	-0.1228	(-0.76)	9.3253	(2.84)*
CLLFRN	-0.1324	(-0.72)	-0.0537	(-0.41)
LGAPPL	0.0573	(2.65)*	0.0375	(2.44)*
LAIRCN	0.0496	(2.16)*	0.0418	(2.57)*
LREMOD	-0.0107	(-0.29)	-0.0199	(-0.76)
LFIRPL	0.0334	(1.27)	-0.0099	(-0.53)
LGARAG	-0.0239	(-1.00)	-0.0140	(-0.83)
LLOTPL	0.3087	(1.72)	0.2731	(2.14)*
LDPARK	-0.0138	(-0.55)	0.0442	(2.49)*
LDJUNK	-0.0317	(1.38)	-0.0103	(-0.63)
MAINST	-0.146	(-0.72)	-0.0292	(2.04)*
LDFILL	0.0464	(1.69)	0.0197	(1.01)
LGWIND	-0.1309	(-2.04)*	-0.0856	(-1.88)
LDTRUK	-0.369	(-0.96)	-0.0545	(-2.00)*
LDFRWY	0.1348	(1.13)	0.0581	(0.69)
LDRAMP	0.1400	(1.18)	0.1337	(1.59)
$\bar{R}^2$	0.675		0.818	
F	21.624		45.689	
D.F.	250		250	

*The figures in parentheses are t-statistics. Asterisks indicate significance at the 5% level on a two-tailed test.

Table 6.8 NAME OF LANDFILL: TUJUNGA

Independent Variables	Dependent Variable*			
	PRICE		ASSVAL	
CONST	-1516.97	(-5.91)*	-72,156.0	(-5.21)*
AGE215	1156.26	(4.94)*	89,708.8	(6.49)*
LOTSIZ	-0.0067	(-2.09)*	-0.4552	(-2.30)*
AREA	0.0673	(5.20)*	6.6481	(8.38)*
BDROOM	-7.7063	(-1.96)*	-201.541	(-0.84)
BTHRUM	12.1749	(1.72)	1682.01	(3.88)*
OTHRUM	-2.3774	(-0.76)	-309.193	(-1.62)
SALDAT	8.1502	(5.30)*	-44.6159	(-0.48)
POOL	-28.7209	(-1.23)	-1164.84	(-0.82)
ODDLOT	0.0013	(0.58)	0.0547	(0.38)
CORNLT	19.4175	(0.60)	-7564.04	(-3.79)*
FRONT	0.1495	(1.48)	15.6751	(2.54)*
CULDSC	34.6758	(0.79)	2920.82	(1.09)
CRFRNT	-0.2299	(-1.12)	30.5504	(2.44)*
CLFRNT	-0.7333	(-0.67)	-33.9963	(-0.51)
APPL	9.0320	(2.82)*	665.670	(3.39)*
AIRCON	9.3877	(2.83)*	708.609	(3.49)*
REMODL	-0.6567	(-0.12)	-235.915	(-0.69)
FIREPL	7.8643	(1.78)	-1.0107	(-0.00)
GARAGE	-3.1240	(-1.03)	-49.5687	(-0.27)
LTSZPL	0.0072	(2.26)*	0.4739	(2.42)*
DPARK	0.0845	(0.35)	30.3960	(2.04)*
DJUNK	-0.6136	(-1.90)	-40.9464	(-2.07)*
MAINST	-3.7207	(-0.76)	-513.560	(-1.72)
DFILL	0.2254	(0.80)	12.7101	(0.73)
WIND	-0.1690	(-1.24)	-8.2178	(-0.99)
DTRUCK	-0.2721	(-0.70)	-43.8028	(-1.85)
DFRWY	0.5158	(0.77)	-10.3803	(-0.25)
DRAMP	0.7562	(1.18)	107.214	(2.78)*
$\bar{R}^2$	0.661		0.824	
F	20.372		47.456	
D.F.	250		250	

*The figures in parentheses are t-statistics. Asterisks indicate significance at the 5% level on a two-tailed test.

Table 6.9 NAME OF LANDFILL: TUJUNGA

Independent Variables	Dependent Variable*			
	LPRICE		LASSVL	
CONST	-0.7050	(-1.24)	6.4170	(19.17)*
LAG215	4.2180	(5.00)*	3.9695	(6.70)*
LLOTSZ	0.0845	(3.38)*	0.0713	(3.79)*
LGAREA	0.4297	(7.54)*	0.4096	(10.02)*
LBDRUM	-0.1015	(-2.50)*	-0.0163	(-0.56)
LBTHRM	0.0588	(1.47)	0.0989	(3.56)*
LOTHRM	-0.0437	(-1.29)	-0.0315	(-1.29)
SALDAT	0.0362	(8.88)*		
LGAPPL	0.0621	(3.01)*	0.0398	(2.63)*
LAIRCN	0.0467	(2.09)*	0.0408	(2.57)*
LGPOOL	0.1391	(4.44)*	-2.1742	(-2.01)*
LDFILL	0.0392	(1.56)	0.0070	(0.38)
LGWIND	-0.1231	(-2.06)*	-0.0793	(-1.79)
LDTRUK	-0.0308	(-0.89)	-0.0428	(-1.63)
LDFRWY	0.1675	(1.47)	0.0805	(1.00)
LDRAMP	0.0406	(0.42)	0.0898	(1.25)
LDPARK			0.0444	(2.54)*
MAINST			-0.0281	(-1.97)*
LLOTPL			0.2624	(2.15)*
$\bar{R}^2$	0.680		0.813	
F	40.309		71.915	
D.F.	263		261	

*The figures in parentheses are t-statistics. Asterisks indicate significance at the 5% level on a two-tailed test.

Sheldon-Arleta

This municipal site is only 60 acres, but it handles over 500,000 tons of solid waste per year (Table 6.1). It is located at the intersection of the Hollywood and Santa Ana Freeways, and thus there are sources of noise unrelated to the landfill operation. The site is bordered on two sides by freeways, one side by a school, and on the fourth side by a residential area. There are a limited number of homes along Sharp Street with a direct view of the site, but because of the flat topography and the elevated freeways on two sides of the site only those homes directly adjacent to the site have any view. The residential area is composed of older homes and is a middle class neighborhood with an occasional rundown house on many of the streets.

This site was started in 1961 and will be turned into a park including Little League fields in about five years. In fact, a small portion of the site has already been turned into baseball fields.

Similar to Tujunga, this area also has low property values. The average sale price of the 179 sample homes was $24,097 and the average assessed value was $21,772. The size of the lot is 7,382 on average and the mean value of the living area is 1,228 square feet. The average number of bedrooms and bathrooms are respectively 2.9 and 1.4. The sample residences are not too far away from the sanitary landfill, the average distance being only one-half mile. However, as mentioned earlier, there are freeways nearby, the average distance being only 1,733 feet.

Tables 6.10, 6.11 and 6.12 present the results of the regression analysis for the 179 sample residences. Because of the lack of availability of data, a number of independent variables had to be excluded from the analysis. These were: view of the fill, distance to the shopping center, down payment, dummy variable for a view lot, quality of construction, and the dummy variables for leasehold and condominium. The results indicate that the included independent variables explain 80 percent of the variation in price, 92 percent of the variation in assessed value, 85 percent of the variation in log(PRICE) and 92 percent of the variation in log(ASSVAL).

Table 6.12 presents the regression results after eliminating most of the insignificant variables, but retaining the variables associated with the sanitary landfill. None of the fill variables are statistically significant in any of the formulations. This could be because these variables are unimportant in explaining the variation in price and assessed value, or because multicollinearity among these variables might be lowering the estimated t-statistics. In order to exclude the latter possibility, we carried out an F-test for the joint significance of the fill variables LDFILL, LDTRUK and LGWIND. The value of F was 0.9 for the dependent variable LPRICE and 2.2 for the dependent variable LASSVL, neither of which are significant because the critical value of F for the 5 percent level of significance is 2.60. We therefore conclude that in the case of Sheldon-Arleta neither the sale price nor the assessed value of a property are significantly affected by the presence of the sanitary landfill.

Although the variables associated with the fill were not statistically significant, a number of other independent variables do have substantial influences on the sale price and assessed value. As in the other neighborhoods, the age of a house is an important determinant of both price and assessed value, with newer homes having higher values. Similarly, the lot size had a substantial effect on both price and assessed value. A 100 percent increase in the size of the lot would have raised the average sale price by 9.3 percent (Table 6.12). This is slightly higher than that of Tujunga which, like Sheldon-Arleta, is a low income neighborhood. The corresponding elasticity for assessed value was 16.2 percent which is considerably higher than the elasticity for price. For the living area, however, the elasticities are nearly the same, with a value of 38.3 percent for price and 36.5 percent for assessed value. These figures are somewhat lower than those for Tujunga. If the lot size is replaced by the size of the yard, the price elasticity with respect to living area becomes 39.0 percent and that for the yard size is 6.6 percent, well below that for lot size.

With LPRICE as the dependent variable, the log of the number of bedrooms had a coefficient that was significantly different from zero, while the log of the number of bathrooms did not. The results for the assessed value regression, however, were exactly the opposite. The number of bathrooms had a significant regression coefficient, but the number of bedrooms did not. The elasticities were also quite different between price and assessed value. For instance, a doubling of the number of bathrooms would have increased the assessed value by 11.6 percent but price by only 4.8 percent. In contrast, a doubling of the number of bedrooms (keeping all other characteristics the same) would have raised the average assessed value by only 3.0 percent whereas it would have increased the sale price by as much as 9.1 percent.

Another interesting contrast between sale price and assessed value is the effect of SALDAT. While, as one would expect, a recently sold house would carry a higher price tag than a similar residence sold earlier, in the case of assessed value the result was the opposite. Other things being constant, a recently sold property has a significantly smaller assessed value than a similar property sold at an earlier date. The same result occurred in the regressions for Palos Verdes.

As Table 6.12 shows, the distance to the park had a negative coefficient. The corresponding t-statistic of -1.81, though, indicates significance at only the 10% level on a two-tailed test. However, if the insignificant landfill variables are eliminated and the resultant equation is re-estimated, this statistic rises above the 5% level in absolute value. In other words, the Sheldon-Arleta residents seem to be willing to pay a higher price for being closer to the neighborhood park. In the case of assessed value this independent variable has no significant effect. The number of built-in appliances does affect both sale price and assessed value substantially. The elasticity for price was 6.7 percent while that for assessed value was somewhat less at 4.1 percent.

Air conditioning also has an appreciable influence on price and assessed value, with nearly identical elasticities.

The addition of central air conditioning to a home with no air conditioning would raise expected price by 4.44 [=100 $(2^{.0396}-1)$] percent and expected assessed value by 4.36 percent. While adding a two-car garage to a residence with no garage would increase its expected sale price by 4.3 percent, the corresponding effect on expected assessed value is not statistically significant.

As one would expect, better maintained houses tend to have higher prices and higher assessed values. The magnitudes of the effects are quite different, however. For example, raising the condition rating of a residence from "average" to "excellent" would be expected to increase its sale price by 6.5 percent, but to increase its assessed value by only 3.2 percent. Similarly, having more than one floor, all other things being equal, has substantial and significant positive effects on both price and assessed value, but it would raise the former by 15.5 percent and the latter by 11.5 percent, on average. On the other hand, the addition of a non-heated swimming pool would raise both expected sale price and expected assessed value by about 10.1 percent.

Interestingly enough, while location on a main street does not significantly affect the sale price of a typical residential property, our estimates show that such a location would serve to lower expected assessed value by nearly 5.5

percent as compared to a similar property not located on a main street. Similarly, a corner lot did not differ much in the sale price but had a significantly smaller assessed value. Although the absolute value of the t-statistics given in Table 6.12 for CORNLT is not above the 5 percent critical level, when the insignificant landfill variables were omitted, CORNLT had a statistically significant negative coefficient. Location in a cul-de-sac, however, had opposite results. It was not a significant determinant of the assessed value of a residence but has a significant positive effect on sale price.

In both the sale price and assessed value models, both distance to the nearest freeway off-ramp and distance to the nearest point on the freeway had positive coefficients. While the coefficient of the former variable was not significant at any reasonable level in either model, it should be noted that these two quantities were very closely correlated in this sample. Doubling the distance to the nearest point on the freeway would raise the expected sale price of a typical residence by 3.5 percent and its expected assessed value by 2.9 percent. Our estimates indicate clearly that residents and potential residents of the Sheldon-Arleta area dislike living near the freeway.

Table 6.10 NAME OF LANDFILL: SHELDON-ARLETA

Independent Variables	Dependent Variable*			
	LPRICE		LASSVL	
CONST	0.7641	(0.96)	4.8975	(7.98)*
LAG215	2.3404	(2.08)*	3.0359	(3.72)*
LLOTSZ	0.1829	(1.20)	0.2032	(1.74)
LGAREA	0.3523	(4.73)*	0.3375	(5.92)*
LBDRUM	0.1085	(2.43)*	0.0412	(1.20)
LBTHRM	0.0581	(1.27)	0.1328	(3.78)*
LOTHRM	0.0375	(0.90)	0.0120	(0.37)
SALDAT	0.0072	(2.21)*	-0.0052	(-1.93)
LGPOOL	1.8169	(1.51)	3.8372	(4.17)*
LODDLT	-0.1198	(-0.59)	0.0808	(0.52)
CORNLT	-0.3241	(-0.39)	1.1391	(1.77)
LFRONT	-0.0043	(-0.02)	0.1040	(0.74)
CULDSC	1.2170	(2.68)*	0.7163	(2.06)*
CRLFRN	0.0445	(0.26)	-0.2373	(-1.81)
CLLFRN	-0.3497	(-2.77)*	-0.2373	(-1.81)
LGAPPL	0.0517	(2.03)*	0.0348	(1.78)
LAIRCN	0.0396	(2.15)*	0.0414	(2.93)*
LREMOD	-0.251	(-0.63)	-0.0607	(-2.00)*
LFIRPL	-0.0384	(-1.23)	0.0131	(-.55)
LGARAG	0.0833	(3.71)*	-0.0152	(-0.90)
FLOORS	4.9893	(1.78)	2.0625	(0.96)
LARFLR	-0.6625	(-1.72)	-0.2696	(-0.91)
LCONDN	0.1302	(3.93)*	0.00667	(2.62)*
LLOTPL	-0.1847	(-1.39)	-0.4097	(-4.02)*
LDPARK	-0.0707	(-2.09)*	-0.0265	(-1.02)
LDJUNK	-0.0047	(-0.08)	0.0767	(1.62)
MAINST	-0.399	(-1.64)	-0.0685	(-3.66)*
LDFILL	0.0461	(1.31)	0.0146	(0.54)
LGWIND	0.0406	(0.72)	0.0243	(0.56)
LDTRUK	-0.0160	(-0.46)	0.0147	(0.55)
LDFRWY	0.0459	(1.82)	0.0458	(2.36)*
LDRAMP	0.0562	(1.10)	0.0159	(0.41)
$\bar{R}^2$	0.847		0.918	
F	32.729		64.904	
D.F.	147		147	

*The figures in parentheses are t-statistics. Asterisks indicate significance at the 5% level on a two-tailed test.

Table 6.11 NAME OF LANDFILL: SHELDON-ARLETA

Independent Variables	Dependent Variable*	
	PRICE	ASSVAL
CONST	-597.544 (-2.10)*	-62,323.5 (-3.47)*
AGE215	542.927 (1.92)	69,666.0 (3.50)*
LOTSIZ	0.0108 (2.48)*	1.4345 (4.49)*
AREA	0.0718 (5.22)*	5.9634 (5.88)*
BDROOM	7.9098 (1.94)	304.697 (1.01)
BTHRUM	7.4455 (0.95)	1939.73 (3.35)*
OTHRUM	4.3414 (1.16)	270.167 (0.98)
SALDAT	1.7944 (2.38)*	-96.5404 (-1.60)
POOL	57.4965 (2.98)*	7435.87 (5.23)*
ODDLOT	-0.6711 (-1.30)	6.5504 (0.17)
CORNLT	-16.0849 (-0.48)	2374.43 (0.97)
FRONT	-0.1714 (-0.46)	2.8518 (0.11)
CULDSC	74.4602 (2.55)*	2223.87 (1.03)
CRFRNT	0.1094 (0.33)	-17.5588 (-0.72)
CLFRNT	-2.4731 (-2.60)*	-86.3865 (-1.23)
APPL	6.6585 (1.85)	434.785 (1.64)
AIRCON	6.0026 (2.42)*	511.450 (2.80)*
REMODL	-4.3982 (-0.73)	-976.798 (-2.20)*
FIREPL	-1.2352 (-0.24)	360.091 (0.95)
GARAGE	9.8802 (3.35)*	-186.434 (-0.87)
FLOORS	192.369 (2.19)*	6061.28 (0.94)
AFLOOR	-0.0967 (-1.65)	-2.3383 (-0.54)
CONDN	13.9752 (4.57)*	752.211 (3.33)*
LTSZPL	-0.0039 (-1.79)	-0.6617 (-4.11)*
DPARK	-0.3362 (-0.54)	3.6574 (0.08)
DJUNK	-1.3245 (-2.32)*	-40.6818 (-0.97)
MAINST	-10.8048 (-1.90)	-1601.47 (-3.82)*
DFILL	0.0006 (0.00)	-6.6928 (-0.12)
WIND	-0.0312 (-0.27)	-4.8122 (-0.57)
DTRUCK	-1.8221 (-2.66)*	-84.8047 (-1.68)
DFRWY	1.3826 (2.39)*	125.574 (2.94)*
DRAMP	0.1750 (0.25)	-20.5574 (-0.40)
$\bar{R}^2$	0.861	0.915
F	36.671	63.087
D.F.	147	147

*The figures in parentheses are t-statistics. Asterisks indicate significance at the 5% level on a two-tailed test.

Table 6.12 NAME OF LANDFILL: SHELDON-ARLETA

Independent Variables	Dependent Variable*			
	LPRICE		LASSVL	
CONST	0.8515	(1.57)	6.3022	(15.15)*
LAG215	2.3297	(2.13)*	3.3353	(4.35)*
LLOTSZ	0.0931	(1.99)*	0.1616	(4.43)*
LGAREA	0.3826	(6.05)*	0.3646	(7.34)*
LBDRUM	0.0909	(2.26)*	0.0299	(0.95)
LBTHRM	0.0479	(1.09)	0.1163	(3.39)*
CULDSC	0.9307	(2.35)*		
SALDAT	0.0080	(2.51)*	-0.0077	(-3.83)*
LDPARK	-0.0568	(-1.81)		
CLLFRN	-0.2711	(-2.32)*		
LGAPPL	0.0672	(2.76)*	0.0414	(2.20)*
LAIRCN	0.0396	(2.24)*	0.0390	(2.83)*
LGARAG	0.0609	(3.37)*		
LCONDN	0.1204	(3.69)*	0.0620	(2.45)*
LGPOOL	0.1382	(4.13)*	0.1399	(5.08)*
FLOORS	0.1441	(2.63)*	0.1091	(2.60)*
LDFRWY	0.0500	(2.17)*	0.0413	(2.47)*
LDRAMP	0.0536	(1.23)	0.0312	(1.16)
LDFILL	0.0300	(0.92)	-0.0164	(-0.69)
LGWIND	0.0387	(0.832)	0.0420	(1.32)
LDTRUK	-0.105	(-0.481)	-0.0254	(-1.55)
MAINST			-0.0563	(-3.03)*
CORNLT			-0.0301	(-1.85)
$\bar{R}^2$	.844		.911	
F	49.088		102.494	
D.F.	158		160	

*The figures in parentheses are t-statistics. Asterisks indicate significance at the 5% level on a two-tailed test.

Calabasas

Although the Calabasas site is large in area, approximately 380 acres, it is currently handling only about 260,000 tons of solid waste per year (Table 6.1). The surrounding area is still rather sparsely populated, thus the site will probably gain volume as the local population density increases. This site is located in the city of Calabasas, about one mile north of the Ventura Freeway (Figure 6.1). The topography of the area is predominantly flat with some gentle hills surrounding the site itself. Thus there are no homes with a direct view of the landfill. There is, however, only one access road to the site, Lost Hills Road, which all the solid waste disposal vehicles must use. This road runs along the boundary of a new housing tract which has been built between the landfill site and the freeway. The tract includes homes in the $40,000 to $60,000 price range, well maintained and landscaped by the residents, making this a very appealing residential setting. This County operated landfill was started in 1957 and is scheduled for completion sometime around 1985; it will then be made into a park or golf course.

The average sale price of the 61 sample residences was $44,800 with an assessessed value of $38,785. Thus this area is second in house values among the four sanitary landfills studies. However, in living area and the average number of bedrooms, bath rooms and other rooms, this tract was the largest of the four areas. The average lot size was 9,994 sq. feet, well below the 12,908 value for Palos Verdes but on the average these have 4.0 bedrooms, 2.7 bath rooms and 3.7 other rooms. In contrast, homes in the Palos Verdes area have 3.4 bedrooms, 2.1 bath rooms and 3.3 other rooms.

Tables 6.13, 6.14 and 6.15 present the results of the regression analysis using LPRICE, LASSVL, PRICE, and ASSVAL as dependent variables. The models used here explain 90 to 92 percent of the variation in log(PRICE) and log(ASSVAL), and 86 to 90 percent of the variation in PRICE and ASSVAL. Table 6.15 presents the coefficients and t-statistics for the double log formulations, after most of the insignificant variables, with the exception of the independent variables associated with the sanitary landfill, have been eliminated. The results of this formulation form the basis for the discussion that follows.

None of the independent variables associated with the sanitary landfill have significant coefficients when LPRICE is the dependent variable. As this may be attributable to multicollinearity involving the fill-related variables, a joint F test of these quantities (LDFILL, LDTRUK, and LGWIND) was performed. The F-statistic was 1.1, well below the critical value at the 5 percent level. We therefore conclude that as far as the sale price is concerned, the presence of the Calabasas sanitary landfill has no statistically significant (positive or negative) effect. In the case of assessed value, however, there is a significant effect. For instance, the distance to the fill variable LDFILL has a significant (at 1 percent confidence level) negative coefficient, implying that the farther away from the fill, the less the assessed value of a residence. A doubling of this distance would lower the assessed value by nearly 22 percent. The corresponding coefficient for price also was negative but not significant at the 5 percent level (significant, however, at the 10 percent level). The distance to the truck route and the number of degrees away from the prevailing downwind from the fill are not significant (even at the 10 percent level) either for price or assessed value.

Unlike any of the other neighborhoods, in Calabasas, the lot size variable has no significant influence on either the price or the assessed values, the reason for which is not clear. The living area, however, is very highly significant. A 100 percent increase in the living area would raise the sale price by 48.7 percent (Table 6.15) and the assessed value by 64.4 percent. Although the number of bedrooms and bath rooms did not show significant effects on the sale price, a joint F-test gives an F-value of 3.86 which is significant at the 5 percent level. The elasticities for sale price with respect to the number of bedrooms and bath rooms are, respectively, 9.5 percent and 6.9 percent. These variables, however, do not have a significant effect on the assessed value, either individually or jointly (the F-value was only 0.4). The number of other rooms was statistically significant for both price and assessed value with positive coefficients. A doubling of the number of other rooms would increase the sale price 25.7 percent whereas they would raise the assessed value by only 11.5 percent.

The presence of a swimming pool also has substantial effects on price and assessed value.

Residences with an unheated pool would have a higher price as well as assessed value than homes without a swimming pool, and homes with a heated pool will have even higher values. The respective elasticities are 15.7 percent for price and 9.7 percent for assessed value. A corner lot location also had a significant positive effect on the sale price, but not on the assessed value. A residence in a corner lot would have, on the average, a sale price about 10 to 10.5 percent higher than a similar one not located on a corner lot. The quality of construction and the condition of maintenance are two other independent variables which had significant regression coefficients in the case of the sale price but not in the case of the assessed value. The elasticity of price with respect to quality of construction was 11.5 percent while that with respect to condition of maintenance was 20.5 percent.

A number of independent variables were excluded from the analysis for Calabasas because the relevant information was not available. These were: view of landfill, distances to the neighborhood park, shopping center and any disamenities, number of appliances, remodeling, and dummy variables for view lot, main street location, cul-de-sac, condominium and leasehold.

Table 6.13 NAME OF LANDFILL: CALABASAS

Independent Variables	Dependent Variable*			
	LPRICE		LASSVL	
CONST	3.2965	(1.30)	10.2051	(2.40)*
LAG215	40.4265	(2.58)*	40.2258	(2.08)*
LLOTSZ	-0.9168	(-2.10)*	-0.7921	(-1.45)
LGAREA	0.4381	(3.85)*	0.6456	(4.54)*
LBDRUM	0.0473	(0.47)	-0.0950	(-0.75)
LBTHRM	0.2356	(2.89)*	0.1432	(1.40)
LOTHRM	0.2414	(2.90)*	0.1200	(1.15)
SALDAT	0.385	(2.20)*	-0.0161	(-1.59)
LGPOOL	22.3124	(1.76)	20.0601	(1.28)
LODDLT	1.2771	(2.11)*	1.1065	(1.46)
CORNLT	10.8827	(1.88)	8.4235	(1.16)
LFRONT	0.8838	(1.75)	0.667	(1.06)
CRLFRN	-2.0967	(-1.81)	-1.606	(-1.11)
LGAPPL	0.1322	(0.66)	-0.0642	(-0.25)
LAIRCN	-0.0399	(-0.73)	-0.0038	(-0.06)
LFIRPL	-0.1281	(-1.87)	-0.0707	(-0.82)
LGARAG	-0.0352	(-0.89)	0.0230	(0.46)
FLOORS	-0.0333	(-0.80)	0.0146	(0.28)
LGQUAL	0.0356	(0.70)	0.0502	(0.79)
LCONDN	0.0714	(0.61)	-0.0695	(-0.47)
LLOTPL	-2.3781	(-1.74)	-2.1467	(-1.28)
DOWNP	0.1764	(1.48)	0.2385	(1.60)
LDFILL	-0.3129	(-0.96)	-0.2730	(-0.67)
LGWIND	-0.0991	(-0.60)	-0.0244	(-0.12)
LDTRUK	-0.0023	(-0.09)	-0.0047	(-0.15)
LDFRWY	-0.1295	(-1.08)	-0.1555	(-1.04)
LDRAMP	-0.0772	(-0.64)	0.0950	(0.63)
$\bar{R}^2$	0.918		0.894	
F	26.700		20.512	
D.F.	34		34	

*The figures in parentheses are t-statistics. Asterisks indicate significance at the 5% level on a two-tailed test.

Table 6.14 NAME OF LANDFILL: CALABASAS

Independent Variables	Dependent Variable*			
	PRICE		ASSVAL	
CONST	-11840.2	(-1.99)	-1,197,980	(-2.01)
AGE215	11499.9	(2.02)	1,305,940	(2.12)*
LOTSIZ	-0.0061	(-0.22)	1.7918	(0.59)
AREA	0.0771	(3.32)*	11.0596	(4.36)*
BDROOM	16.7044	(1.20)	-1008.37	(-0.66)
BTHRUM	23.3779	(1.55)	1201.33	(0.73)
OTHRUM	25.7683	(1.96)	1755.08	(1.22)
SALDAT	8.3192	(1.24)	-618.240	(-1.40)
POOL	146.594	(0.50)	31,298.3	(0.99)
ODDLOT	5.3481	(2.07)*	297.505	(1.06)
CORNLT	489.269	(1.73)	11,398.0	(0.37)
FRONT	1.9524	(1.53)	27.5307	(0.20)
CRFRNT	-3.2130	(-1.49)	-27.6338	(-0.12)
APPL	-0.2298	(-0.01)	-2269.19	(-0.59)
AIRCON	-8.8553	(-0.65)	189.335	(0.13)
FIREPL	-8.6902	(-0.53)	-717.650	(-0.40)
GARAGE	-14.7552	(-1.57)	230.316	(0.23)
FLOORS	-3.8574	(-0.20)	939.046	(0.44)
QUALTY	15.7738	(1.53)	724.162	(0.64)
CONDN	17.1163	(1.12)	-17.5375	(-0.01)
LTSZPL	-0.0084	(-0.31)	-2.7202	(-0.92)
DOWNP	90.8317	(1.53)	9287.13	(1.43)
DFILL	-0.4387	(-0.06)	-659.647	(-0.85)
WIND	0.4848	(0.30)	44.5255	(0.25)
DTRUCK	-0.8700	(-0.18)	-263.024	(-0.49)
DFRWY	2.2921	(0.25)	-958.192	(-0.96)
DRAMP	-3.9030	(-0.77)	642.157	(1.17)
$\bar{R}^2$	0.900		0.868	
F	21.710		16.116	
D.F.	34		34	

*The figures in parentheses are t-statistics. Asterisks indicate significance at the 5% level on a two-tailed test.

Table 6.15 NAME OF LANDFILL: CALABASAS

Independent Variables	Dependent Variable*			
	LPRICE		LASSVL	
CONST	2.1593	(2.25)*	6.3815	(5.72)*
LAG215	11.8274	(2.70)*	16.1180	(3.04)*
LLOTSZ	-0.0132	(-0.30)	-0.0101	(-0.21)
LGAREA	0.4873	(5.76)*	0.6444	(6.82)*
LBDRUM	0.0947	(1.43)	0.0583	(0.85)
LBTHRM	0.0686	(1.21)	-0.0029	(-0.05)
LOTHRM	0.2565	(5.36)*	0.1147	(2.08)*
LGPOOL	0.1571	(3.51)*	0.0967	(2.11)*
LBQUAL	0.1151	(2.74)*		
LCONDN	0.2053	(2.50)*		
CORNLOT	0.0987	(1.95)		
LDFILL	-0.1353	(-1.73)	-0.2199	(-2.89)*
LDTRUK	-0.0228	(-0.95)	-0.0173	(-0.62)
LGWIND	0.1262	(0.98)	0.1592	(1.10)
$\bar{R}^2$	0.901		0.890	
F	42.939		49.755	
D.F.	47		50	

*The figures in parentheses are t-statistics. Asterisks indicate significance at the 5% level on a two-tailed test.

E. SUMMARY OF RESULTS

In this section we summarize the results obtained from the analysis of data for residential areas in the proximity of sanitary landfills. Regression models designed to explain variation in property values were estimated separately for each fill area. Four explanatory variables were included in the model in order to account for the effects of each fill on the prices and assessed values of nearby residential properties. The estimated coefficients for these fill variables from the regressions in double log form are summarized in Tables 6.16 and 6.17.

Table 6.16 ELASTICITY OF PRICE WITH RESPECT TO FILL VARIABLES

Variable	Palos Verde	Tijunga	Sheldon-Arleta	Calabasas
Distance from fill	-.07*	.04	.03	-.14
Direct view of fill	.03*	NA	NA	NA
Distance from truck route	.03*	-.03	-.01	-.02
Degrees away from downwind	-.01	-.12*	.03	.13

* Significantly different from zero at 95 percent confidence level.

Table 6.17 ELASTICITY OF ASSESSED VALUE WITH RESPECT TO FILL VARIABLES

Variable	Palos Verde	Tijunga	Sheldon-Arleta	Calabasas
Distance from fill	-.04*	.01	-.02	-.22*
Direct view of fill	.03	NA	NA	NA
Distance from truck route	.04*	-.04	-.03	-.02
Degrees away from downwind	.15*	-.08	.04	.16

* Significantly different from zero at 95 percent confidence level.

The general conclusion suggested by these results is that these four sanitary landfills have not had significant detrimental effects on surrounding property values. In the cases of Tijunga, Sheldon-Arleta and Calabasas there were no significant coefficients which were consistent with the hypothesis that sanitary landfills have harmful environmental impacts. In the case of Palos Verde, proximity to the truck route was associated with lower property values, but this negative impact seems to be dominated by the positive impacts of being near to and having a view of the fill which results, presumably, from the anticipation of the future use of the fill site for recreational purposes.

Further insight into these findings may be gained by recalling some of the discussions in earlier chapters. As Chapters II and V stressed, the basic hypothesis underlying studies of this sort is that if external effects are properly perceived and understood, they will be reflected in the rental values of impacted properties. Since, as Chapter IV has stressed, the matter of ground water pollution is quite complex, it would not be reasonable to expect a property value study to capture related external damages, even if they are in fact important.

Further, available data provide information on property values, not on explicit or implicit rents. These values are logically viewed as having been obtained by capitalizing the relevant streams of benefits or (explicit or implicit) rents at some discount rate. These facts have two main implications. First, if one wants to derive a dollar measure of damages, it is necessary to consider the relationship between this discount rate and the socially appropriate discount rate. Since the present study is mainly interested in whether damages in fact exist, this issue does not arise here. Second, since we can only observe, at best, the present value of the changes in benefit streams brought about by the proximity of the landfill, it is difficult or impossible to infer anything about the change in benefits at any single point in time. This issue arises in connection with Palos Verdes, where we argued that proximity to the disposal site presumably lowers benefits for a few future years and raises them thereafter. Our results suggest that the resultant change in present value is positive, but they can say nothing about the absolute magnitude of current costs or future benefits.

Further, as Chapter II stressed, even if these problems did not exist, estimates such as ours could not be used by themselves to compute dollar values of landfill-related externalities. In theory, any change in the relative attractiveness of various parcels of land will bring about shifts in the pattern of land use throughout the relevant market area. In order to derive a defensible measure of external costs, these shifts must be predicted. While approximations and shortcuts do exist, they must be used with extreme care.

We are aware of only two other attempts to evaluate the external effects of solid waste disposal sites; both were discussed in Chapter III. The study by Goldberg, et al [6] takes a very different approach from ours. Their use of control neighborhoods is questionable on empirical grounds, and their focus on changes in property values over time has no theoretical justification.

The paper by Havlicek, Richardson, and Davies [5], hereafter referred to as HRD, is much closer in spirit to our study. Both relate various attributes of residential properties, including proximity to solid waste disposal sites, to property values. Because of data limitations, neither is able to investigate the Anderson-Crocker [1] contention that owner characteristics, in particular income, belong in such regressions. There are a number of important differences between these studies, however.

First, HRD used a linear specification throughout. We have discussed at length above the shortcomings of this specification, and we regard our log-linear model as more sensible. The weakness of the linear specification is especially clear with respect to the "distance from the site" variable. According to the HRD estimates, each foot one moves away from the disposal site adds the same dollar amount to property value, regardless of the original distance or of any characteristics of the property. This is surely unreasonable. Another weakness in their specification is their treatment of the age variable. Even though they cite Emerson [4], HRD make no use of his analysis of this quantity, and age enters linearly into their regressions.

Second, our analysis had the advantage of a much richer data base. The HRD sample consisted of 182 residences, while ours included a total of 966 homes. While HRD considered only 12 attributes of individual properties, we analyzed over 40. The fact that we had more information suggests that our results may be more reliable. It should be understood, however, that, strictly speaking, our estimates pertain only to the sites we actually studied. Solid waste disposal sites differ enormously, and our findings clearly cannot be asserted to apply to all sites everywhere without considerable additional research.

Finally, while neither study employed data on neighborhood characteristics, the problem of differences among disposal sites and their surrounding neighborhoods was handled very differently. HRD simply pooled all their observations, even though they related to five different sites, and, thus five different neighborhoods. They allowed intercepts but not slopes to differ among the five groups. In particular, the external effects of all five disposal sites were assumed identical on the margin. Our analysis, on the other hand, treated each landfill separately. All the homes considered at any one time belonged to the same general neighborhood and were affected, if at all, by the same disposal site. There was thus no need to control for characteristics of individual neighborhoods or landfills. Our regression results confirmed our initial suspicions: individual variables did indeed have different impacts on property values in different neighborhoods. This suggests that, at least in our sample, pooling of the HRD sort would have been quite inappropriate. Whether this is true for their sample and whether their results are accordingly biased, we have no way of knowing.

The foregoing comparisons should not be interpreted as suggesting that the HRD effort was worthless. Theirs was truly a pioneering study, and we learned a great deal from careful consideration of its strengths and weaknesses. Still, we feel safe in asserting that the research reported here represents an advance over the HRD study.

The regression models we employed were specified after considerable theoretical analysis, and they explained high proportions of the variance in observed property values. For the most part the explanatory variables had coefficients that were consistent with the predictions of economic theory, and some of the landfill-related variables had significant and explicable coefficients. These results support the contention that the external effects that can be perceived by actual and potential property owners will be reflected in market values and can be evaluated by fitting a properly specified econometric model to data on the values and characteristics of affected properties.

Obviously, as a general matter, more work needs to be done on modelling the way in which property characteristics determine property values. In particular, a good case can be made for the explicit use of nonlinear estimation techniques in such models. Further, additional research is needed to gather and evaluate data on solid waste disposal site characteristics that are likely to reflect external effects. This study indicates that such efforts, if done with care, are likely to yield meaningful results.

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